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Proceedings of the CIB World Building Congress 2016

Volume IV

Understanding impacts and functioning of different solutions

Edited by

Suvi Nenonen

Juha-Matti Junnonen



TAMPERE UNIVERSITY OF TECHNOLOGY



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Preface

Volume four includes 58 paper contributions linked to the congress sub-theme “Understanding impacts and functioning of different solutions”. The proceedings provides insights to six sub themes. First of all the sustainable impacts are discussed from the perspectives of energy use and energy management. The diverse solution over the globe like sustainable housing in Colombia and a Net Zero Energy Building in Finland provide insights to culture specific issues.

The second theme is dedicated for the papers about building information modeling. Different phases of construction process are approached in diverse articles. Also this theme has an international flavors: research from Ethiopia and Singapore is presented among many other interesting papers. The third theme is about diverse working environments: in the office, at the schools and in connection with healthcare. Also housing and mobility are discussed.

The fourth theme includes economical case studies as well as issues connected to calculations with interesting insights to cost estimations to assessments and issues about infrastructure management. The fifth theme is focusing on construction projects especially in terms of productivity, networks and partnerships as well as regulations and norms. Also ever-green topic of lean production is touched in various papers. Finally the sixth theme is about diverse solutions: roofs, thermal conditions and ventilation have inspired the researchers. This book has hilarious amount of interesting papers from different countries and research organizations. In order to provide some key figures the amount of papers is among the themes following.

I Sustainability	8 papers
II Building information modelling	15 papers
III Work environments	6 papers
IV Economics and construction	9 papers
V Construction projects	12 papers
VI Solutions	8 papers

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May 2016

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May 2016

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Building Codes and Demand Response of Energy Use

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Abstract

Buildings are an essential part of the wider energy system. A significant share of electricity consumption occurs in buildings. Traditionally buildings have been places where electricity is consumed. Now they have a growing role also as a location where renewable energy production, such as solar power, occurs.

Demand response means the voluntary actions that are taken on the customer side as a response to something on the demand side. In practice, demand response can involve, for example, reducing the energy consumption during the peak times of the larger energy system or shifting the timing of the building's energy consumption by synchronizing it with local renewable energy production's profile inside the building. The building codes of Finland direct the designers' energy-related solutions both in new construction and licenced renovations.

In this conceptual paper the literature related to demand response and regulation is reviewed, and it is discussed what kind of a role the building codes could have in advancing the buildings' preconditions for demand response. Demand response is currently brought out in EU directives in the regulation with relation to network operators. However, preparedness for demand response could also be advanced by giving more attention to the timing of power use in the building codes.

Keywords: Building Codes, Demand Response, Energy Law, Energy Use, Power

1. Introduction

The balance between supply and demand in electricity networks has traditionally been achieved mainly by controlling the output power of generators. However, the role of the demand side may be growing. According to the newer paradigm, the system can be more efficient and environmentally friendly if also the fluctuations of demands are controlled (Albadi and El-Saadany, 2008).

Historically, night-rate electricity (and seasonal time of use) tariffs have been time-based incentives that encourage the timing of electricity consumption to those periods of the day or year when consumption without such pricing incentives would be lower. Hot water dispensers and both fully and partially storage heating systems in buildings have been tuned to work at night especially in many of the buildings built in Finland after the 1970s. A more recent step is electricity exchange (Nord Pool)-based consumer energy pricing, which has become increasingly popular. Electricity prices vary seasonally, daily, and hourly in the electricity markets; this variation is based on many factors, including the estimated balance situation (demand and supply). Building's energy consumption varies during different hours (Dirks et al., 2015; Vihola et al., 2015). Market price signal-based demand response can aid in the balance between supply and demand on the wider energy system.

In the future, a growing share of the electricity production will be based on intermittent generation with variable power output (Brouwer et al., 2014). The possibilities of managing the energy system by controlling the production side of electricity are more limited when the share of weather-dependent renewable energy resources (i.e., wind and solar) increases in the energy system. This is especially the case when the power is expected to be flexible upwards. Thus, there is a growing need for managing the demand-side resources of the built environment, including controllable loads, energy storages, and small-scale power generation. As a result, buildings that have been passive consumers in the energy system are expected to be more active and flexible parts of future smart energy systems (Bulut et al., 2015). At the same time, it is possible that profile of peak electricity demands in the building stock will change in the future (Dirks et al., 2015).

It is estimated that buildings account for approximately 20-40 % of energy consumption in different countries (Pérez-Lombard et al., 2008;), representing approximately 32 % of the worldwide energy demand and approximately 39 % of the total energy consumption in Europe (Allouhi et al., 2015). The need to increase the energy efficiency of buildings is nowadays recognized, and presently, energy regulations of buildings are under change. New houses should be “near zero energy buildings” (nZEB) in the European Union (EU) countries in the near future, following directive 2010/31/EU. Exceptions of this requirement include the smallest buildings and buildings that are intended to be used annually for a limited time; otherwise, most of the heated new buildings will be at least nZEB level in the future. “Near zero energy” regulations are a step towards meeting more energy-efficient requirements. The aim of the nZEB level building codes is to increase the energy efficiency of buildings and the share of energy that is produced from renewable sources. In practice, those requirements will likely

increase the share of weather-dependent and small-scale energy production, e.g. solar energy and heating pumps and, in the built environment, which can influence the entire energy system.

2. Basics, advantages and problems of demand response

According to Darby et al. (2013), there are three approaches by which smart grids can reduce greenhouse emissions: (1) reduction of demand alias energy efficiency, (2) reduction of demand at peak times, and (3) increased penetration of renewable energy generation. In smart grids, it is possible to manage and reduce the demand peaks by changing the demand loads in such situations that previously were and currently are handled with energy generation from fossil energy sources. After the Paris Agreement in 2015 regarding global average temperature development, there will probably be growing pressure to develop energy systems towards such solutions that reduce greenhouse gas emissions.

Demand response (DR) denotes several types of voluntary actions that are taken on the customer side as a response to something in the energy system (Torriti et al., 2010). In practice, demand response can mean, for example, shifting energy consumption to a different time or reducing the energy consumption during the peak times in the larger energy system. The execution of demand response can be based on the energy price signal or, for example, on reliability (i.e., system security, capacity, or power balance based needs)-based actions (Aghaei and Alizadeh, 2013). Humans can have either an active role in controlling the loads in demand response or more passive roles, if DR is based, for example, on automated load shifting (Torriti, 2014). End users can have an active role, if households are, for example, scheduling their cooking times based on energy prices. Possible loads for automated load shifting, i.e., shifting that the end user does not necessarily even notice, when DR occurs can include the heating loads of buildings or boilers.

There are several papers on demand response from the perspectives of electricity retailers, distributors, producers, users, and DR technology (Kim and Shcherbakova 2011; Ruester et al., 2015; Shariatzadeh et al., 2015); however, the role of building codes has thus far nearly always been missing from studies related to DR and its opportunity to become more popular. In this paper, we consider how the demand response might be advanced by building codes and the instructions related to them. The regulation examples are written especially from the Finnish perspective, but many of them are also applicable in many other countries. The focus in this paper is on the forms of demand response actions where the end user can have a rather passive role: in this case, the holder of a building's electrical interface might need to commit to take DR in use but not personally or actively follow the demand situation.

By DR it is possible to affect environmental impacts of energy production. DR can aid in reducing CO₂ and other emissions if it is utilized to change the timing of energy use from the peaks, when fossil energy is utilized more frequently in the energy system, to those times when fossil energy sources are not needed as much (Cardell and Anderson, 2015; Gilbraith and Powers, 2013).

Smarter demand response actions were previously possible for only large energy users, e.g., industrial actors; however, with technological development, the situation may be changing (Ruester et al., 2014). One development is that there are currently some technological preconditions in the buildings, such as smart meters and other solutions, that can enable the use of real-time price information concerning individual consumers' consumption; the lack of such preconditions was earlier seen as a potential barrier to the realization of DR (Torriti et al., 2010). In addition, the amount and role of distributed energy generation is growing (Ruester et al., 2014), which can increase the need for DR. It can be most profitable for the building's owner if, for example, the solar energy produced in a nearby building is at least for the most part also used in that building. Such a situation requires synchronizing at least part of building's energy consumption with the local fluctuating energy production.

There are several technological possibilities for implementing load control in practice. In addition to smart meters, larger buildings normally have some type of building automation system. Technically, DR can be carried out by smart meters or separate appliances, e.g., a home energy management system (HEMS). Also for example electric alternations can be utilized in managing or controlling demand need variations inside the building.

DR can provide different advantages for different market players in the energy system. These advantages include system level power balance and frequency control for the transmission system operator; portfolio optimization and novel pricing structures for the electricity retailer; peak cutting for the distribution system operator; and new possibilities for minimizing the purchase costs of electricity for the end user (Aghaei and Alizadeh, 2013; Shariatzadeh et al., 2015). If DR cuts the peak demands and improves the reliability of the energy system, then it can also reduce the need for additional power plants and committing capital costs to those investments (Siano, 2014). Feuerriegel and Neuman (Feuerriegel and Neumann, 2014) argue that the financial benefit of DR could increase in the future due to rising energy prices, increasing price volatility at different times, and regulatory reasons (Feuerriegel and Neumann, 2014). The possible advantages of DR include the following:

- **End user:** Decreasing electricity purchase costs, optimizing the utilization of energy produced in users' local power plants, and optimizing the size of the main fuse.
- **Retailer:** Optimization of the procurement of the electricity (portfolio optimisation), management of the balance between procurement and sales, novel products and pricing structures, and new business opportunities (e.g., operating as aggregator).
- **Distribution System Operator (DSO):** Peak cutting in normal and disturbance situations, using demand response as a substitute for back-up lines, and optimizing the dimensioning of the network.
- **Transmission System Operator (TSO):** System-level power balance and frequency control (balancing and reserve power) in normal and disturbance situations.

Both the amount and the reaction time of demand-side resources are important from the perspective of energy system management. The speed at which the load can be changed based on demand affects that capacity's market value (Valtonen, 2015). In addition, the length of the possible elasticity is meaningful for its value.

Significant potential DR resources in Finnish buildings include the electric heating loads of detached houses and ventilation, cooling, and lighting in larger buildings. When utilizing demand response, several types of restrictions must be considered, e.g., indoor air quality (Alimohammadisagvand et al., Forthcoming). In addition, pre-heating of cars, supplementary electric heaters, greenhouses, and freezing plants provide load control resources.

Currently, in Finland, almost every electric customer has a smart meter (~97%), which is remotely readable, registers hourly consumption, and has some load control enabling functionalities. Furthermore, the balance settlement is based on the measured hourly energy consumption of the end-users. It is estimated that Finland could currently have approximately 1800 MW of such controllable loads via smart meters, which are, in principle, technically ready for the utilization of DR, but in practice, there are obstacles for utilizing it (Honkapuro et al., 2015).

Several market places for DR and other flexible resources already exist in Finland. There are the day-ahead (Elsport) and intra-day (Elbas) energy markets offered by electricity exchange (Nord Pool) and the balancing and frequency-controlled reserve power markets offered by TSO (Fingrid Oyj). However, the holders of buildings or apartments are normally not wholesale electricity market parties. Thus, they cannot sell their own loads directly to these electricity markets; instead, they require a third party to join that market and connecting potential loads together. The business ecosystem for DR should be further developed, though some possibilities for smaller electricity users to participate in DR have recently emerged.

Though time-based pricing (night-rate tariff) was popular even before the electricity markets opened and although DR has been part of industrial and academic discussion for some time, a more developed, energy-market-based DR has not been rapidly adopted. Electricity market parties do not appear to have high incentive for developing DR markets. According to Kim and Shcherbakova, the main challenges that DR programs have met can be classified as consumer, producer, and structural barriers. Consumer barriers include the consumer's knowledge, the availability of required technology, fatigue related to continuously responding, technological costs, and the low level of real savings, whereas structural barriers include rate structures, technology, regulatory process, and policy support (Kim and Shcherbakova, 2011).

Greening argued that the reason for slow popularization of DR is not technical by nature and recommended that state regulators regulate DR by developing incentive mechanisms to promote the utilization rate of DR (Greening, 2010). Van Dievel et al. (2014) noted that the consumer privacy issue can also be one potential barrier to the use of demand response for both investors and consumers. The execution of demand response goes hand in hand with accurate

consumption data, and these data can include private information. Further, the potential rebound effects after demand reductions must be managed (Fuller et al., 2011)

There can also be conflicting interests between the retailer and DSO that can make the realization of DR more difficult. These conflicting interests have been analysed, for example, in network simulations (Rautiainen, 2015) that examined how peak loads in real-life network would change if the electric heating of the households were controlled according to the market prices of different market places. According to the results, the peak loads of the distribution network would increase if the loads were controlled based only on the market prices.

Cottwald et al. (2011) reported that DR also has potential for producing new challenges, e.g., new types of peaks in energy system. Energy-price-based demand response can change both the load profile in the distribution network and the conflict of interest situations between stakeholders. If a distribution tariff is structured based on the power maximums instead of energy use, then customers are also provided incentives to decrease their peak powers (Rautiainen, 2015). Hence, this kind of tariff would prevent the market-based load control from negatively impacting the peak power of the network. If customers are incentivized to optimize their loads according to both the system price and the distribution network load in such a way that tariffs support the total energy efficiency of an energy system, then more environmentally positive outcomes can result.

3. Demand Response and EU Directives

Demand response is a new approach from the perspective of legal regulation. Present market rules for flexibility in the electricity markets were created in a context when demand response was not real alternative for generation-side resources (Koliou et al., 2014).

In the EU's most recent energy efficiency directives, some changes seem to be occurring compared to earlier energy policy. According to Butenko and Sceres, there is currently "significant discrepancy between the dominant concept of the consumer as adopted in the hard and in the soft EU energy law" (Butenko and Cseres, 2015). In particular, in some of the soft-law-type documents produced in the EU, the position of consumers appears to be more active than before: there, consumers are described as active providers of demand response services to the markets. In addition, in the Energy Efficiency Directive (2012), the consumer's role is presented as somehow active providers, whereas in many other directives, consumers are seen as more passive (Butenko and Cseres, 2015). In directive 2012/27/EU, the significance of demand response in developing energy efficiency is explained as follows:

*"Demand response is an important instrument for improving energy efficiency, since it significantly increases the **opportunities for consumers or third parties nominated by them to take action on consumption and billing information** and thus provides a mechanism to reduce or shift consumption, resulting in energy savings in both final consumption and, through the more optimal use of networks and generation assets, in energy generation, transmission and distribution."*

In the same directive (2012/27/EU), in article 15, it is required that European Union's member states should ensure *“the removal those incentives in transmission and distribution tariffs... that might hamper participation of demand response, in balancing markets and ancillary services procurement”*, *“that network operators are incentivised to improve efficiency in infrastructure design and operation, and, within the framework of Directive 2009/72/EC, that tariffs allow suppliers to improve consumer participation in system efficiency, including demand response, depending on national circumstances”*, *“national energy regulatory authorities encourage demand side resources, such as demand response, to participate alongside supply in wholesale and retail markets”* and *“promote access to and participation of demand response in balancing, reserve and other system services markets, inter alia by requiring national energy regulatory authorities or, where their national regulatory systems so require, transmission system operators and distribution system operators in close cooperation with demand service providers and consumers, to define technical modalities for participation in these markets on the basis of the technical requirements of these markets and the capabilities of demand response”*.

Thus, the Energy Efficiency directive sets requirements for network and retail operators to promote demand response by their pricing tariffs. In annex XI of the same directive, time-of-use tariffs, critical peak pricing, real time pricing, and peak time rebates are mentioned as examples of network or retail tariffs that could support dynamic pricing for demand response measures. However, this directive does not set requirements for building designers or for the consumer side related to demand response.

Network regulation (Agrell et al., 2013) and energy market regulation solutions are important tools when promoting demand response. However, in the literature, little attention has been paid to how demand response could be promoted in buildings by building codes and by buildings' original designers. In this paper, it is argued that preconditions of demand response could be promoted by building codes among other regulation instruments. Next, we examine this subject using Finland's building codes as a case example.

4. Building Codes and Energy Efficiency

Lee & Yik classified instruments encouraging energy efficiency in buildings into three categories: (1) building energy codes, (2) incentive-based schemes, and (3) eco-labelling schemes (Lee and Yik, 2004). Building codes affect buildings' design and construction processes and, thus, its features aside from land use planning regulations. Incentives include energy taxation and energy renovation aids; in addition, energy certificates can be seen as examples of eco-labelling.

Buildings codes have a meaningful role in reducing the energy consumption of buildings (Scott et al., 2015). The use of mandatory building codes in encouraging energy savings in the buildings became widespread in the 1970s after the energy crisis. (Allouhi et al., 2015; Lee and Yik, 2004). These building codes are currently widely used instruments, especially in many developed countries, and are used among other things to control the energy consumption levels of new or renovated buildings (Iwano and Mwashu, 2010; Salvalai et al., 2015). The content of

building codes varies in different countries and areas, where climate conditions and local needs can differ. Building codes are applied in the design and construction phases of new and renovated buildings; however, such codes are not necessarily able to give orders regarding the use of the buildings or buildings products, for which different legal instruments should be used. The legal status of building codes also varies in different places: their status is mandatory in some countries or areas, voluntary in others, and mixed in still others (Iwaro and Mwasha, 2010).

In Finland, building codes (see Building Codes of Finland) have traditionally included both mandatory rules and voluntary instructions in the same documents; however, the situation is changing, and there is ongoing a process for separating mandatory parts from instruction parts by 2017. All mandatory parts of the building codes will be in the future given by decrees of the Ministry of the Environment in Finland. In this paper, both the mandatory and instruction parts given by the responsible ministry or government are called building codes.

Finland's valid Land use and construction act (117 g §) mandates the Ministry of the Environment giving building decrees about the minimum requirements for energy efficiency in buildings; building products and technical systems and their calculation methods; heating systems in buildings; improving energy efficiency; measuring energy consumption; and the minimum energy efficiency requirements based on a building's intended utilization. Mandatory regulation regarding the electricity use of buildings is focused on safety issues and is given in documents that are not classified as building codes. HPAC issues are addressed in the building codes.

Building codes of Finland are applied when building licence is sought. Building codes guide the designers' solutions, and consequently the features of the buildings. When it comes to the many details of the energy systems, building professionals make several decisions for the end users. related to the details of buildings' energy systems. Thus the designers and electricians may play a key role in how DR-ready the new or renovated buildings will be or whether DR features are utilized. However, the building codes and the design solutions can impact the user behaviour only partly and indirectly in the utilization phase.

Even though building codes are currently instruments that can be used also in encouraging towards energy efficiency, their role in predefining the probable load profile of buildings' energy use has not often been dealt with. Plans of new buildings have to be in accordance with regulations. Current building codes in Finland set limits for computational annual energy use in new buildings, which is calculated based on plan documents. However, timing profile of energy use inside the year or energy load profile of building has no weight in current regulations.

5. Discussion

Through building codes it is possible to set requirements for technical solutions or technical readiness issues in buildings, to guide the selection of building products utilized in buildings, and also for example determine the targets, objects and methods of energy calculations. Table 1 provides some examples how demand response capabilities in new or renovated buildings could possibly be advanced by building codes. The cost efficiency and effectiveness of the means presented in the table are not analysed in this paper. It could be a theme for further research.

The ways how demand response capabilities in the buildings could possibly be advanced by building codes could include for example changes in minimal technical requirements; changes in the other details of energy efficiency incentives; and changes in things that influence designers', buyers' and public officers' awareness of the power behaviour of buildings and how it can be affected by design solutions. In principle, it is possible to respond by demand on many levels, including the energy market level, the distribution network, and the building's own electric network. Also the regulating means listed in Table 1 can have targets on different levels.

Table 1: Examples of how readiness for demand response could possibly be advanced by building codes (or voluntary actions related to them)

Means of regulation	Object of impact	Example
Defining the technical requirements so that readiness for DR grows in the buildings	Technical solutions and possibilities to exploit DR	Massive structures and boilers are often able to store heat energy in building, which can be utilized in DR. However, if HVAC systems are not easily ready for DR, those capacities are not so likely utilized.
Requiring that power use efficiency is noted when performing the energy calculations required for building licence	Power use behaviour of buildings	Target values for the electric power use could be set both for peak and empty use times of buildings for daily hours and different seasons. Those values could be calculated when the energy calculations of buildings are performed anyway.
Taking into account DR when determining the primary energy factors per energy carrier	Energy certification class & profitability of DR investments	Lower primary energy factors per energy carrier could be utilized for electricity in the primary energy calculations if DR are considered in the design
Instructions for synchronizing distributed local renewable energy production and energy use inside the building	Timing of energy use in comparison to timing of local energy production	The DR features of appliances could be encouraged to put into operation, when they have such
Instructions or recommendations for power management inside buildings	Power fluctuation management inside the building	It could be encouraged that especially larger loads, e.g., sauna stoves and heating pumps, are alternated to limit the probabilities of sharp power peaks in the energy demand of the building

Currently, the building codes of Finland concentrate on annual energy consumption, and the timing of the consumption or the power peaks do not play a significant role. However, as noted in the literature review, the timing of consumption can be an environmentally significant issue, and influence, for example, the greenhouse gas emissions of energy production and wider energy systems. Technical solutions affect some DR capabilities. For example thermally massive structures can slow temperature changes in a building and add the possibility of changing the timing of heating. To guide the designers' and building owners' attention towards the power use instead of annual energy use alone, some target power values could be set and calculated for both peak and empty use times that could be taken into account in the design phase.

One idea that we have proposed as an incentive for DR is that lower primary energy factors per energy carrier (see 2010/31/EU, Annex 1) could be utilized for electricity in the primary energy calculations if DR was utilized. The basic idea behind those primary energy factors is to encourage reduction of the total primary energy consumption and to promote the share of renewable energy sources. If DR could help to reduce the consumption of non-renewable energy sources, then this fact might be an argument for applicability of lower computational factors. The values for those factors are nationally appointed in the member states of EU. In Finland, those factors are given as a Government Decree and published also among the building codes.

The aim of the instructions for synchronizing distributed local renewable energy production and energy use inside a building is to direct the demand inside the building towards the production time and power profile of local energy production. The same technical structure for demand response system might be applicable in other levels and types of DR. In the present smart electricity meters, there are some readiness features for demand controlling that could, in principle, be utilized in some type of DR. However, those features are often not installed for use or are not utilized if they are installed.

In Finland, the electric sauna stove and heating systems of several residential houses have been alternated via the electric installations for decades without legal commands. Those alternations have reduced the power peaks inside the building and needs for larger fuse size. However, omission of such alternations has nowadays become more common in new buildings. Building codes have not traditionally regulated electric installations in Finland, but the power behaviour of buildings could be at least indirectly guided also by building codes.

When developing regulation related to DR, also the risk aspects must be considered so that the regulation wouldn't, for example, lead to such new losses that do not exceed the benefits obtained from the perspective of total energy efficiency. For example it is possible that if DR readiness is required by mandatory regulation, the features may not in all cases be utilized in practice, at least if DR features are not sufficiently economically profitable or easy enough to use. When developing regulation, also technological development and new types of future solutions for power management should be somehow taken into account. The focus in this paper

has been in such types of demand management that do not require the end user to play an active role in the using phase of the building's life cycle. However, the building's owner or user may need to make decisions whether the DR features are utilized in the building or not.

6. Conclusions

From the perspective of total energy efficiency of energy systems, it could be useful if the power aspects were considered more in the design phase of buildings in addition to annual energy use examination. Regulation by building codes is not the only possible approach for affecting preconditions of DR, but it can be one piece of the larger puzzle, which includes also for example information issues, taxation solutions, tariff structures in distribution network and energy market regulation.

Although the load profiles of different building types vary in different countries, the need for load management and demand response ability may grow worldwide as the structure of energy production is changing towards a more renewable nature. Further research is needed about the connections of DR and effectiveness of regulation in the built environment.

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Regulations

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Modelling for efficiency in energy management of the building life

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Abstract

Energy efficiency is a requirement included in building for the future constructions; modelling tools to manage the design, construction and maintenance of the building are available to assure quality in the process by controlling the interaction between disciplines connected with the built environment (i.e. architectural design, structural design, MEP design). The building construction management and the durability screening of the building can be improved and optimized by the BIM techniques that can also become an efficient tool to check the economic aspects during the building lifespan. The energy consumption during the running phase is the focus of possible future contract of building quality and the possibility of providing accurate and robust performance analysis, including prediction of uncertainties and variations related to change of use and occupants' profiles will become dramatically important. Define procedures and tools to provide a connection between models used in the design and management phases of the building with the objective of minimize the energy discrepancy between energy prediction in the project phase and actual energy consumption in the operating phase are accordingly the aim of the paper towards future energy assurance contracts. The paper describes the tested procedures to outline interoperability paths between BIM and BEM models with different software providing workflows that can be suitable in different design processes and work phases. The easiest process cannot be the more accurate and a results comparison with test reliability procedures can improve the reproducibility of the process and modelling strategies to facilitate the interaction between analysis tools at different levels.

Keywords: BIM to BEM workflow, energy efficiency, Building Information Modelling, Building Energy Modelling, Energy contract

1. Introduction

The housing crisis shifted the focus of the building sector from new construction to existing assets. International studies about energy retrofiting show the benefit of benchmarking in improving the energy efficiency during time. Benchmarking is the collection, comparison and sharing of building energy use data and ratings and can lead to an improvement of energy saving about 7% in few years (Vancouver Council, 2014; IEA-ECBCS, 2011). The use of digital methods to manage the design process allows the integration of multi-objective analyses (Asadi et al., 2012) (i.e. architectural, structural, MEP, energy modelling) into a main chain of information enhancing the effectiveness and the accuracy of the design, construction and management processes. Compared evaluation of multi-options scenarios and crosschecks between disciplines on a same BIM model (Building Information Model) can reduce time and cost due to variants and adjustments in the construction site.

The aim to prevent inconsistencies occurring in the standard design process led the BIM into the limelight in the public procurement as is explicit in the European Directive 2014/24/UE, art. 22/4 that states: “4. For public works contracts and design contests, Member States may require the use of specific electronic tools, such as of building information electronic modelling tools or similar...”. Consequently, the BIM model adopted to manage the whole building process in a wide-sense life cycle approach includes additionally the energy management of the building. The energy item should be included in the BIM model since it could be a key factor in the building contracting. The building energy compliance to evolving regulation towards more and more restrictive thresholds of consumption during the lifespan of the building needs powerful tools that redraw the building status when maintenance changings occur. If there is an envelope improvement and/or a HVAC system replacement as well as the requirement to provide energy retrofit measures, the possibility to run a BEM model connected to BIM information is crucial both in existing and new constructions.

The residential and tertiary buildings have the considerably weight of 40% in the final energy consumption of the European Union (Directive 2010/31/EU). Energy reduction of about 30% of energy consumption of the building sector is mandatory in European directives to reach the 20-20-20 Climate-Energy Package (Directive 2009/87/EC) objectives. Furthermore, energy and environmental policies require greenhouse gas emissions reduction by at least 40%, a growing renewable energy production and energy efficiency by 27% (European Commission, 2030 Framework, 2013). The main field of implementation for energy efficiency is related to the new constructions as the renovation rate of the complete building stock is 1.1% and the existing buildings interested by retrofit represent about 1.8% (Ascione *et al.*, 2012) of the total amount. Additionally, renovation strategies should be based on cost-optimality criteria (BPIE, 2010).

Northern European countries commonly use the BIM model to manage public contracts and it is widely adopted at national level; nevertheless, a dissemination phase is still required. BIM tools enhance and optimize the interconnections between actors and stakeholders of a project allowing the rationalization of the different phases: design and programming, project management, construction, operation, maintenance and budget (East et al., 2013). In term of

energy efficiency BIM is an influential tool to include the control and reduction of the energy consumption of the building during the design phase and running phase decreasing the related costs and environmental impacts. Therefore, the connection and interoperability of BIM (Building Energy Modelling) to BEM (Building Energy Modelling) is a key point to share information and results for development purposes between the experts in the involved fields. Furthermore, the reliability of the energy simulation and result is an additional issue when energy requirements are part of a sale or rent contract; currently the energy certificate of a building or an apartment is mandatory in these kind of trades.

2. BIM to BEM

The BIM federated model can be the information base or the main store of the data allowing designers to perform structural, MEP, energy analyses. According to BIM uses, the development of the input requirements permits to cover the more fields of knowledge. For an effective BIM to BEM workflow, reducing data loss, the correct information for energy modelling has to define the building information model according to the different stages of the project (COBIM 2012, Series 10). The possibility to use the same information included in the BIM model directly into the BEM model provides a guarantee in minimizing the discrepancy and loss of information between the two models. The need to implement the information, usually not included, in the architectural model, requires as first the cooperation in the team work of the energy analyst with the architectural team in a starting phase of the design (with positive consequences) and the enrichment of the model with energy information such as:

- a) thermo-physical characteristics of the envelope materials;
- b) specification of window energy performance;
- c) space uses to identify homogeneous thermal zones;
- d) thermal loads due to the specific use of the different thermal zones;
- e) ventilation rates of the thermal zones (per occupant or space size criteria);
- f) set point temperatures of the thermal zones;
- g) HVAC systems for the building and for each thermal zone.

An additional information related to energy issues is the value of the embodied energy for each material, the data sheet for specific products (e.g. phase change materials, membranes, etc.) that can be useful to qualify the energy model; however, this information has to be post-processed in the BEM modelling phase. The relevance of a unique repository of structured information is the basis for the organized and shared set of data belonging to all the concerned parts. BIM allows the comparison of system configurations, to compute components (e.g. pipes, plants, etc.) by metric automatic calculation and to connect data sheets to the plant components or other elements of the project. The BEM simulation can provide a strong criterion in the decision process, when energy saving strategies to pursue economic targets are included.

The paper provides a list of BIM to BEM workflows with commercial available software to deliver enlightenment about this data interchange process. The research work aims in identify the most promising interoperability paths. The methodology adopted is explained in the following section 3 in which the interoperability workflows are discussed.

3. Methodology

3.1 BIM software

The BIM software used as starting point is Autodesk Revit, a BIM platform widely used in the professional and research field of construction and digitalization of the design, construction and operating phase of a building life cycle. Different BEM tools imported the output from Autodesk Revit to test the workflows. In section 6 the discussion of strengths and weakness for each software is reported considering the following indicators:

- Usability;
- Accessibility;
- Accuracy;
- Geometry import;
- Envelope thermal features;
- HVAC setup;
- Model export;
- Parametrization;
- Compatibility.

3.2 BEM software

The review of the BIM to BEM workflow does not claim to be exhaustive; however, the provided review covers much of the most significant options today available in the digital land for energy modelling in the professional field and advanced research. The tested energy simulation software are listed below:

- Autodesk Green Building Studio;
- SketchUp / Energy Plus;
- Design Builder;
- Grasshopper / Honeybee.

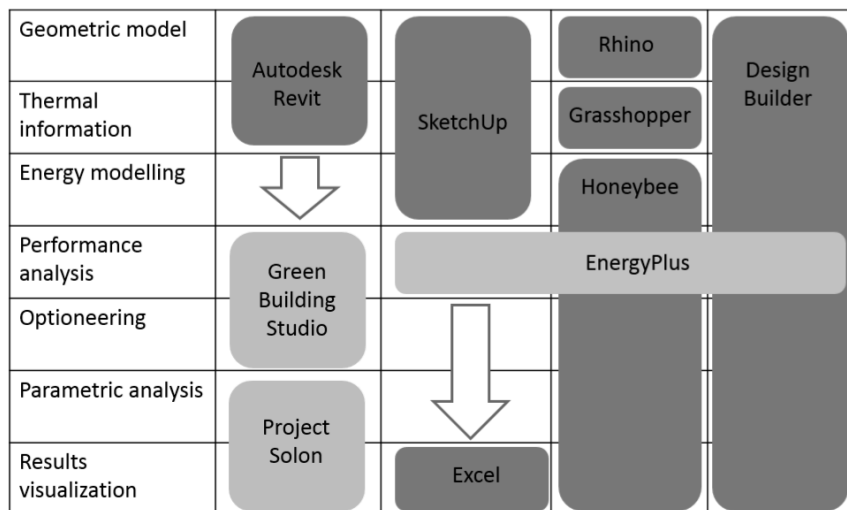


Figure 1: Digital tools used to manage different phases of the analysis process.

3.3 Research process




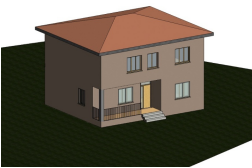
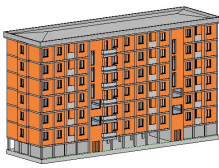

The work process has been structured by applying to three residential case studies, described in section 4, the different workflows following standard steps:

- Preliminary analysis of the project in order to evaluate the suitable thermal zoning (heated and unheated zones, shading surfaces, etc.) and thermal data collection (materials data);
- Realization of the BIM model of the buildings with thermal homogeneous spaces (spaces, rooms) to apply thermal zoning;
- Definition in the BIM model of the thermal characteristics of the envelope materials and components (both opaque and transparent);
- Setting of the heated and unheated zones in the BIM model (temperature set-point, internal loads due to people, appliances, ventilation rates, HVAC type applied to the thermal zone);
- Energy analysis within the software Autodesk Revit using the Energy Analysis form exporting to Autodesk Green Building Studio; then Green Building Studio can export Energy Plus software standard files (*.idf file);
- Import of the exported information to Energy Plus software, procedure of information transfer, tracking/checking/detection of critical issues;
- Realization of energy models into the listed software and reliability comparison of the results to assess the user friendliness, accessibility and robustness of the process.

4. Case studies

The three residential case studies are representative of the main problems extensively diffused in the existing building stock at national level considering the age of construction and technology. The buildings are located in northern Italy, in the city of Brescia (latitude 45.54°N, longitude 10.22°E). The sizes range from a detached house (Castenedolo) to apartment building (social housing in Casazza) to double family detached houses (social housing Case Marcolini), as shown in Table 1.

Table 1: Case studies located in Brescia province, Italy.

	<i>Single family house, Castenedolo</i>	<i>Social Housing, Casazza</i>	<i>Double family “Case Marcolini” settlement</i>
<i>Actual building</i>			
<i>BIM model</i>			

5. Workflows

The tested workflows are described in the following sub-sections. The simpler workflow is the basic one from Autodesk Revit to Autodesk Green Building Studio through the Energy Analysis toolbar. This workflow allows a first analysis and an output file to perform detailed simulations in EnergyPlus software. Moreover, other accredited energy software widespread adopted have been tested considering the criteria listed above in sub-section 3.1 and the goal was to achieve the detailed dynamic simulation with EnergyPlus software (LBNL, California).

5.1 Autodesk Revit to Green Building Studio

The energy simulation of the building takes place in the cloud using a special form in the main Autodesk Revit toolbar. As first, a detailed BIM parametric model of the buildings have been created. An accurate BIM library of materials, with defined thermal properties, has been used as basis to design the envelope. Internal loads, ventilation rates, detailed schedules of use and thermal plant features have been selected for each thermal zone. The “Spaces” tool permits to identify and describe the rooms as thermal zones. Autodesk Green Building Studio (GBS) has been used to analyze the buildings. The simulation in GBS runs 40 parallel parametric options of the project introducing variation in different parameters to evaluate the variability of the energy performance based on ASHRAE standard requirements. This tool is very powerful and the application of the Project Solon panel allows an effective results vitalization and communication. Project Solon is an experimental customizable interface to create dashboards and set up specific graphs and comparison chart used to manage and report the data about the energy performance. However, the user must carefully control the settings to export the model in Autodesk Revit to the GBS platform because the application is organized such as to give default settings to the model for the analysis and often the inexperienced user cannot be so aware to avoid uncontrolled change/overwriting in the model features. The information are equipped of additional considerations that can be misleading for unprofessional user. The GBS tool allows a simple interoperability path giving access to the project team to the energy analysis in a smart way, it must be underlined the need of a supervision and verification process by energy experts.

5.2 Autodesk Revit to EnergyPlus (through GBS)

From the first workflow the EnergyPlus compatible file (file *.idf) has been exported. The file imported in EnergyPlus software has been verified to verify the data transfer. Three BIM to BEM models have been tested using different level of detail in the BIM model as listed below:

- Detailed architectural model;
- Simplified architectural model;
- Conceptual mass model.

The data transfer process from BIM model to EnergyPlus allowed successfully importing of the energy characteristics of the layers of the vertical walls, while errors occurred in the importation of floors and windows characteristics. Furthermore, the visualization of the model into the graphical interface SketchUp allowed pointing out serious problems in the intersections between

the interior partitions and exterior walls and floors due to model specification in the “Spaces” configuration. The high level of detail of the BIM model is not always an advantage in the BEM model and sometimes a simplification, without significantly outcome on the energy results, is required to enhance compatibility. For this reason, a simplified parametric model has been realized and compared to the detailed one. In this way, it was possible to achieve an improvement in geometry transfer. Finally, a conceptual mass model has been analyzed. In this model, it is possible to simplify the assignment of energy characteristics even though with default constructions. These constrains leads to a time-expensive post process of the file in the EnergyPlus interface (EP-Lunch) due to the change in the naming transfer process that modify all the elements’ name given in the BIM model, beyond the fact that the actual envelope characteristics have to be manually implemented.

5.3 SketchUp to Energy Plus

Upon the data transfer problems between Autodesk Revit and EnergyPlus, an alternative model in SketchUp has been developed and tested. SketchUp is a graphical interface used for the geometrical Modelling for Open Studio (NREL). On the same concept, the plug-in BESTenergy (Politecnico di Milano) allows to run EnergyPlus simulations through a simplified modelling in SketchUp. The geometrical model has been constructed as sum of adjacent thermal zones supplied by thermal characteristics of the envelope, internal gains and ventilation rates, schedule and temperature set points. The model allows to extract demands of sensible heating and cooling. The *.idf file exported from GBS has been tested in Open Studio and BESTenergy; however, problems in identification of materials, geometry, schedule for varying parameters and simulation setting have been reported and time-expensive procedure of adjusting have been compared to the “starting from zero” modelling process. The process is simplified (in comparison with direct use of EnergyPlus software) and transparent (compared to GBS process) easing the hourly dynamic energy simulation effort. When modelling errors or lacks are detected, the software generates a detailed list of errors that have to be corrected in order to successfully run the simulation. As opposite, in the GBS model the lacks are automatically corrected with default construction and settings allowing the energy simulation. This process enables the simulation on the other hand could contemporary lead to modelling errors out of user’s control. Results can be organized in graphs and communicated through *.xls file data post-processing.

5.4 Rhinoceros to Honeybee (through Grasshopper)

An alternative workflow has been to model the geometry of the buildings into the software Rhinoceros, using the component Grasshopper and simulate the energy behavior through the plug-in Honeybee running EnergyPlus simulations. The file can be exported directly as *.idf file and as *.gbXML file through GrizzlyBear (Core Studio, 2015). This workflow was lunched with the aim of creating an energy model defined by algorithmic components of Grasshopper in order to subsequently develop retrofit solutions through the parametric solver Galapagos. The creation of the model is a time-expensive process requiring hardworking effort due to the software’s complexity. In particular, the schedules’ management has been reported as

particularly complicated. It is possible to visualize and customize the output into Honeybee plug-in in order to underline the relationship between energy parameters (e.g. wall insulation/energy performance). The values of the results are comparable with results coming from other tools and actual energy bills (section 6), even so further verification on the accuracy of the data to calibrate the models and test of robustness of the interoperability process have to be applied.

5.5 Autodesk Revit to Design Builder

The parametric BIM model realized in Autodesk Revit can be directly exported by an add-in button to Design Builder software or through *.gbXML file. Design Builder is a complete commercial product including EnergyPlus thermal simulation, daylighting simulation, CFD and optimization tool (using JEPlus, a Java shell for EnergyPlus parametric analyses). The software can export *.idf file for direct use in EnergyPlus software. The Autodesk Revit to Design Builder add-in button allows transferring the correct geometry of the building; however, some problems in thermal characteristics of the envelope data transfer occur in multi-zone models. In single-zone models, a complete transfer of thermal properties of the stratigraphy of the wall through “Rooms” tool (instead of “Spaces” tool) could be verified however, other specifications cannot be included in this setting. The schedules’ settings (internal gains, ventilation rates and set point temperatures) and thermal plant have been setup in Design Builder software. Expertise in energy modelling specifically for thermal HVAC systems and operating is required to manage correctly the software and results analysis. A set of standard results visualization is available into the software. The exported *.idf file is compatible in EnergyPlus (through an updating process in the EnergyPlus utility form).

6. Discussion

The tests carried out showed that information requirements in terms of energy analysis need a careful management, especially considering the quality of data implemented in BIM platforms used by designers (COBIM 2012, Series 10). Revit model has not to present a high LOD (level of detail), in order to reduce errors in the information workflow. At minimum, the architectural model has to define spaces and rooms. Some of the tested BIM-to-BEM workflows required the creation of a separate geometry model containing all the necessary energy requirements. The export file must essentially include features related to energy analysis by reducing them to essential data for the specific analysis in order to not burden the *.idf file transfer with information that may be distorted and compromise the successfully processing of the analysis within EnergyPlus software. The SketchUp plug-in can be extremely useful for displaying the geometry problem of data transfer that could not be pointed out directly in EnergyPlus interface (EP-Lunch). The interchange *.idf files created by GBS are not directly useable and a hard work of adjustment of the exported files turns into more convenient to restart to model into compatible graphical interfaces with EnergyPlus (SketchUp plug-in) or including it (Honeybee, Design Builder). In this way, the compatibility of the file is complete.

Design Builder is the most directly connected BIM to BEM model tool in the present review, however manually implementation of some data setting is required. A full interoperability occurs between Autodesk tools (Revit to GBS), although the reliability of energy calculations is not easily verified and comparison of results with actual data shows significant discrepancies (Figure 2).

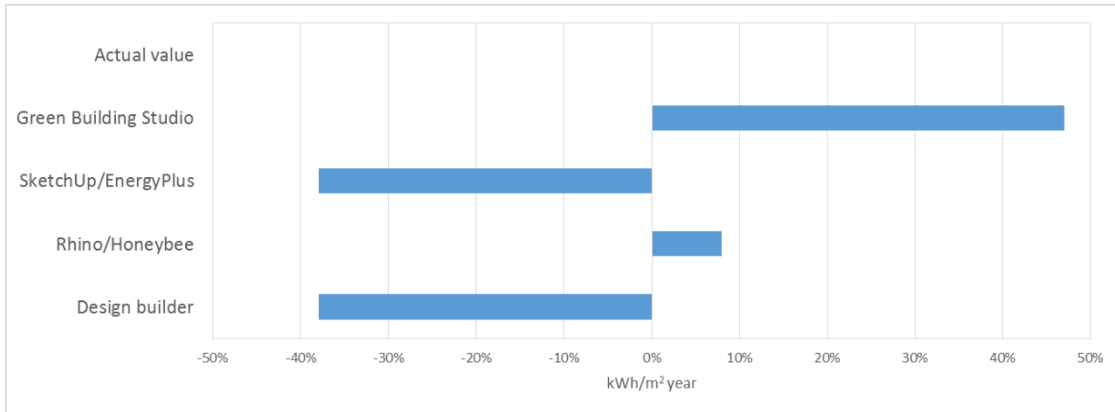


Figure 2: Energy results comparison between BEM software and actual results (energy bill).

Directly use of energy simulation software allows a parallel workflow starting from traditional data. The challenge is to find out an uninterrupted information flow even in both direction assuring reliable results. Interoperability workflow based on the *.gbXML format, such as the Autodesk Revit to Design Builder, can guarantee consistent results even though a detailed set up process of the thermal zone has to be performed. This workflow connects Autodesk Revit model to EnergyPlus (version 8.2) through a working *.idf file without additional adjustments, as is instead required for the *.idf file exported by GBS.

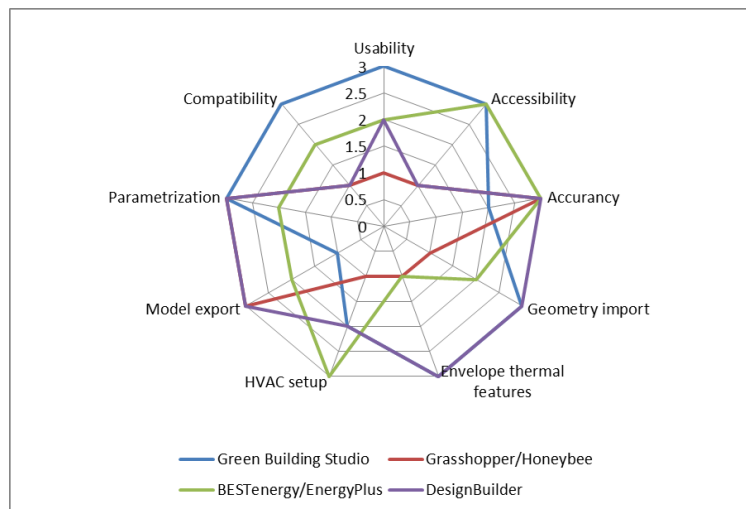


Figure 3: Spider diagram: evaluation of the BIM to BEM workflows.

Thermal zone properties defined in the BIM model can be also exported by using the interoperability workflows proposed in this research. For example, thermal properties can be added to spaces for energy analysis in Autodesk Revit. Geometrical attributes can be added in

Revit rooms. Both geometrical and thermal properties can be imported in Design Builder by the *.gbXML format, but more tests have to be completed on this data flow. The Industry Foundation Classes (ISO 16739:2013) IFC-based BIM to BEM workflow has been initially tested to be used with software Energy Plus (EnergyPlus™, 2013) through SkeethUp interface, e.g. BESTEnergy (Aste et al., 2012) and Open Studio (Parker et al., 2014). However, it has not been resulted as a user-friendly option so far if compared to the results of other workflows. Further tests will be conducted as future works, especially for the IFC-based data flow Open Studio/SketchUp.

7. Conclusions

The research aims to evaluate the reliability and usability of workflows to ensure energy analyses for buildings in a market scenario in which the BIM model will be the reference database for the whole management of the asset. Issues as maintenance, LCC (Life Cycle Cost), LCA (Life Cycle Analysis), energy management and standard compliance can be controlled through the same exhaustive repository of a central federated model. In this scenario, the data sharing between all the actors of design and built management processes promotes the integration of skills and information without lack of knowledge. This can be achieved through interoperability processes and including platforms, especially if they are based on neutral data formats.

Nowadays, energy simulation are required to be dynamic in order to detail on hourly basis the energy behavior of the building. The Net Zero Energy Building task needs a tailored design, an accurate construction and a structured management to reduce the variability of the energy consumption due to factors introducing a fluctuation of the energy needs (i.e. user behavior, control of the running parameters vs. designed parameters, built quality, etc.). Finally, the possibility to carry out a monitoring phase of the energy consumptions through sensors installation connecting them to the BIM model could be the further step to manage the whole life of the building in a holistic vision and to calibrate the predictive models (Miller et al., 2014).

The performance gap commonly occurring in comparing energy simulation results and actual energy bills needs a crossing by providing a reliable model on which energy contracts could be based. Moreover, the information-based technologies allow visualizing, sharing and comparing data that become strong decision drivers for energy strategies and policies. Subsequently with the evolving energy regulations the energy performance of the building turned into a discriminating factor for the building sector market and the evaluation of the whole quality of the asset together with economical (that is strictly related) and location and space flexibility criteria. Standard test procedures ANSI/ASHRAE 140 and Regression test for Energy Results validation are decisive to evaluate and to define the consistency of prediction results; however, tests on real buildings to calibrate the model are not avoidable.

An informed use of energy simulation tools, based on the knowledge of physical and thermal exchange phenomena, is fundamental for the user to be able to crosscheck results using

simplified models. Anyway the validation of input data is the first check to correctly predict, with a uncertainty rate, the energy result, in order to guarantee consistency between input and output (to avoid the “garbage in – garbage out” effect). For this reason, a solid knowledge of limits of the interoperability workflows can be seen as a core interest in the applied research. In this direction, the laser scanner technology integrated with BIM model is a step to survey existing building providing transparent and validated geometrical data.

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Environmental Assessments in the Built Environment: How Reliable Are They?

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Abstract

Assessing the environmental consequences of using and developing the built environment is becoming more and more important. A huge problem is that in many cases the assessment methods are not well-enough developed to lead to credible results. Life cycle assessment (LCA) is one of the most widely used assessment approaches and it is believed to deliver reliable data. Still, two assessments can lead to very different outcomes even when following high academic rigor. In this study, a streamlined LCA to greenhouse gases (GHGs) was utilized to demonstrate certain problematic perspectives in the state-of-the-art of environmental assessments in the built environment. The focus of the study was on buildings and especially on the assessments of embodied GHGs in buildings, which provide an abundance of great examples of problematic issues. In the study, three examples are presented of situations where the reliability of the results of a certain study is questionable: (1) a wooden frame window, (2) a steel body passenger elevator, and (3) a multi-story concrete frame residential building. The particular uncertainty/error perspectives discussed are truncation error in conventional process LCAs in different assessment cases and the assessment scope differences between different studies. Through discussion the case results are positioned to depict the problems on a wider scale. The particular perspective with novelty value for the truncation error discussion is the so-called “first tier truncation error”, which has received very little attention so far. The error arises if, for example, a certain building item, is assessed according to the different materials needed. The assessment de facto does not take into account the actual window manufacturing stage, resulting as an additional downwards bias.

Keywords: Built environment, environmental assessment, life cycle assessment, LCA, uncertainty

1. Introduction

Assessing the environmental consequences of using and developing the built environment is becoming more and more important. Developing our settlements sustainable is one of the grand challenges of our time (Rees and Wackernagel 1996; Seto et al. 2014). Climate change mitigation has already grown into an aspect to consider at virtually all levels of decision-making (Säynäjoki et al. 2014), and new global problem areas like biodiversity loss are gaining attention (Steffen et al. 2015). The environmental issues have penetrated into the processes of the users and developers of the built environment, and various assessments are run on regular basis to understand the environmental impacts of certain actions or activities and to compare different options (Säynäjoki et al. 2015). The huge problem is that these assessments are believed to produce reliable information, and the results are utilized to justify decisions and draw policy-guidelines, when actually both the quality of a high share of these assessments and often even our state-of-the-art in assessing certain impacts are not high enough to lead to credible results.

Life cycle assessment (LCA) has established a strong position among the environmental assessments and it is believed to deliver reliable data. Still two assessments can lead to very different outcomes even when following high academic rigor (Suh et al. 2004), and many assessments are lacking this quality. With other assessment approaches, similar and even more worrisome examples can easily be found. It is not even rare that a new study suggests entirely different impact factors to be utilized than the current tradition to assess the impacts of a certain action or activity.

In this study, a streamlined LCA to greenhouse gases (GHGs) is utilized to demonstrate certain problematic perspectives in the state-of-the-art of environmental assessments in the built environment. The focus of the study is on buildings and especially on the assessments of embodied GHGs in buildings, which provide an abundance of great examples. In the study, three examples are presented of situations where the reliability of LCA method in the built environment context is questionable: (1) a wooden frame window, (2) a steel body passenger elevator, and (3) a multi-story concrete frame residential building. The particular uncertainty/error perspectives discussed are truncation error in conventional process LCAs in different assessment cases and the assessment scope differences between different studies. Through discussion the case results are positioned to depict the problems on a wider scale. The particular perspective with novelty value for the truncation error discussion is the so-called “first tier truncation error”, which is present in the majority of building and civil structure LCAs but has received very little attention so far. The first tier truncation error arises, if e.g. a certain building item, like window, is assessed according to the contributions of the different materials needed. The assessment does not take into account the actual window manufacturing stage, resulting as an additional downwards bias (in addition to the “traditional” truncation error inherent to all process LCAs).

The remainder of the paper is arranged as follows. In Section 2 the main LCA approaches are presented with the emphasis on the qualities potentially leading to biases and errors in the assessments. Section 3 presents the demonstration cases and the data. Section 4 shows the

results and Section 5 provides discussion about the key issues. Section 6 presents some key conclusions.

2. Method

According to its name, LCA estimates the environmental burdens of goods, services or processes over their life cycle from cradle (e.g. raw materials extraction) to grave (e.g. disposal or recycling) (Klöpffer 1997). The method has been developed since the '60s (e.g. Hunt and Franklin 1996), but the use in the building sector has increased rapidly since the '90s at least in terms of number of academic publications (Fava 2006; Sartori and Hestnes 2007; Buyle et al. 2013; Sharma et al. 2011). There are two main approaches to LCA: process and input-output (IO) LCA. Both have their strengths and weaknesses, but are inherently different, potentially leading to very different assessment outcomes (e.g. Lenzen 2000). Here the methods are only briefly summarized, and the focus in the next sections is on the particular weaknesses which may add significant uncertainty to the results.

2.1 Process LCA

Process LCA is the traditional, most widely utilized, method for an LCA (e.g. Suh et al. 2004). Process LCA utilizes material quantities to estimate the impacts related to their production. The environmental data are typically taken from existing databases such as ecoinvent or GaBi. The method is held as accurate due to its quantity basis and the high-resolution material distinguishing ability. At the same time, however, the method suffers from an inherent truncation error from certain higher-order phases of the production and delivery chains being virtually always left outside the assessment boundary (e.g. Suh et al. 2004; Matthews et al. 2008). Lenzen (2000) has suggested these cut-offs to be quite significant overall, and in one of the very few building LCA comparisons Lenzen and Treloar (2002) suggest the error as potentially being 50% or even more in that context. Junnila (2006) has demonstrated the cut-offs to be significant in the service industries.

Another, much less discussed, issue is that there actually is a “first tier truncation error” quite typically present as well in process LCAs (Heinonen et al. 2016), particularly in the context of the built environment. When items are assessed through the material quantities, the final production and assembly phase might be omitted, especially in the case of pre-manufactured items utilized in the production of the assessment object, such as electricity and piping systems or elevators in a building. The material quantities omit potentially an important share of high-degree processing leading to a significant “first tier truncation error”. This issue will be discussed through the selected assessment examples of this study.

2.2 Input-Output LCA

IO LCA assesses the environmental impacts based on monetary transactions and the spreading of the value-added through the economy. IO LCAs utilize environmentally-extended economic transaction matrixes (i.e. IO tables), which allow for summarizing the overall impact caused by

a transaction on one sector based on how the value-added spreads through the economy. IO LCA is typically based on the IO tables of national accounts, although multi-region models exist nowadays. The method was first introduced by Leontief (1970) in the '70s. IO LCA achieves a theoretical full system completeness since an infinite number of upstream processes are inherently included (e.g. Suh et al. 2004). However, as Lenzen (2000) presents, IO LCAs don't inherently include the use and disposal phases (the life cycle ends at the factory gate) and thus they also suffer from a kind of a truncation error without amendatory actions.

The method suffers from several inherent problems. The most important are aggregation error and homogeneity and linearity assumptions. Aggregation error arises from the fact that each IO sector actually is just a weighted average of the emissions intensities of multiple sectors of an actual economy (e.g. Suh et al. 2004, Crawford 2009). Thus the intensity might randomly over- or underestimate the actual emissions from the assessment object. Homogeneity assumption means that all the products within an IO sector have the same emissions intensity. Linearity assumption refers to the inherent assumption of IO models that the exchange price would have linear correlation with the emissions, which in many cases doesn't hold true (Girod and de Haan 2009). IO LCA is thus a tool for assessments of average products and systems.

3. Research Design

In the study, three examples are presented of situations where the reliability of the LCA method in the built environment context is questionable: (1) a wooden frame window, (2) a steel body passenger elevator, and (3) a multi-story concrete frame residential building. Next each example is presented.

3.1 Wooden Frame Window

As depicted in the method section, one feature of process LCAs is the so-called "first tier truncation error". In this study the potential impact of this error is depicted with a case of a wooden frame window 1.2x1.9 m. The case window is a business-as-usual northern latitude triple-glazed window with insulation gas (argon) and wooden frames with the outer frame covered with aluminum. The insulation gas is omitted from the assessment as having a negligible climate change impact. The glass is assumed to be 4 mm uncoated flat glass and the frame 80x210 mm. In between the glass layers are aluminum board frames. The estimated material volumes are:

Glass	54.3 kg
Wood	29.3 kg
Aluminum	6.7 kg

The process LCA approach and SimaPro with ecoinvent 2.0 database (PRé Consultants 2010) are utilized in the assessment to compare two different assessment approaches. The first option is an assessment utilizing a traditional process LCA approach in calculating the quantities of wood, glass and aluminium and summarizing the contribution of each to the overall result. This

approach is by far the most utilized when the window is assessed as one item of a building but leads to the so-called “first tier truncation error” presented in Section 2.1. As the second option, the same window is assessed utilizing theecoinvent 2.2 sector “Window frame, wood U = 1.5 W/m²K, at plant”. This sector includes the final production sector (first tier), and should suffer only from the traditional truncation error of process LCAs, thus enabling conclusions on the significance of the so-called “first tier truncation error”. It is of course obvious that there might be other differences in the two approaches hindering this particular error from showing. For example, the binding materials in the window frame or the paint are not taken into account in the first type of approach, but this is a very typical cut-off in an LCA study in the building sector and just aggravates the problem of underestimation of the first approach.

3.2 Steel Body Passenger Elevator

The second case depicts the often significant difference between the two main LCA approaches, process LCA and IO LCA. An elevator is a great example of a case where the inventory of the main materials for a process LCA captures only a limited share of the actual overall GHGs related to the manufacture and assembly of the elevator. The production requires a significant amount of high quality processing in between the materials and the ready product, which is not fully captured with such typical building LCA approaches where the main material quantities are assessed in the LCI phase and given emissions intensities according to an LCA database. Overall it is thus a good representative for both types of truncation error that process LCAs can lead to. IO LCA for its part then again includes also the capital goods and overall does not suffer from the truncation error.

In this study a comparison was run between (1) a traditional process LCA with a bill of material quantities for a modern steel body elevator for a five-story residential building, and (2) the same elevator assessed with the IO LCA method utilizing the U.S. economy based EIO-LCA (Carnegie-Mellon University 2008) adjusted for inflation and the currency exchange rate. The estimated bill of quantities and the cost estimate for the elevator were:

Cables, doors, rails	1,000 kg
Motor	300 kg
Elevator body	700 kg
Cost	25,000 €

3.3 Concrete Frame Multi-Story Residential Building

The third case studied was a concrete frame multi-story residential building. The comparison builds on a literature review of the published case results from the academic literature. A total of 16 cases were found for comparison, presenting a huge variation in the results, not explained by the case characteristics but rather by the differences and uncertainties in the LCA methods. The cases are not presented one by one but rather the range of results together with a discussion of the utilized assessment approach.

For comparability, one m² of gross space was utilized as the functional unit. If only net areas of the case buildings were reported, these were converted into gross areas using a conversion multiplier of 1.43 m² based on Lylykangas et al. (2013). This was also in accordance with the respective ratio taken from Passer et al. (2012). In the cases when the original paper presents the results in embodied energy rather than in GHGs, a conversion factor of 0.266 kg CO₂e per kWh was utilized taken from the EIO-LCA tool of Carnegie Mellon University (2008). For reliability, the factor was also compared to Junnila et al. (2006) and Fuller and Crawford (2011), who give estimates of 0.24 kg/kWh and 0.25 kg/kWh.

4. Results

4.1 Wooden Frame Window

The two assessments returned significantly different results. For the three main materials the GHG LCA estimate is approximately 130 kg CO₂e, whereas the wooden-frame window sector of ecoinvent 2.0 gives an estimate of 300 kg CO₂e for the case window. It is obvious that the two assessments are not identical in their scopes since the material-approach excludes, for example, paint, glue, handles and hinges and is thus downwards biased in comparison to the window sector. The difference is still striking, however, and gives indications for two important issues: (1) the “first tier truncation error” (see Section 2.1) can potentially be of high importance in building LCAs, which tend to omit the final production phase of many items; (2) the main materials might in many cases not lead to a sufficient scope. The first issue is present with important systems and items of a building, e.g. with the electrical system in general, piping and fixed furniture. Heinonen et al. (2016) depict how these categories might have an important impact for the LCA results and should not be cut off as is often done, but it is alarming if the truncation errors are of this magnitude if only the main materials without the final production phase are included.

4.2 Steel Body Passenger Elevator

The steel body passenger elevator case demonstrates how different results the two LCA approaches, process LCA and IO LCA, can return. The process LCA result is approximately 5,500 kg CO₂e, whereas the IO LCA result is almost 14,000 kg CO₂e. Again a couple of important conclusions can be made. (1) While process LCA inherently leads to an underestimation of the actual emissions due to the truncation error, an elevator is a perfect example of an item in a building with which the main materials can only capture a considerably limited share of the actual overall emissions. In addition to the inherent traditional truncation error, the “first tier truncation” can be high. (2) A significant amount of materials is left out from such traditional assessments which only include the main materials, as in this study, and altogether these cut-offs can create a significant additional truncation error. (3) The IO LCA can randomly over- or underestimate the actual emissions due to the aggregation error, but this cannot easily be checked, and due to its quality of including a substantially wider scope than process LCA (e.g. the capital goods), an important share of the difference in these two results is likely to be due to the underestimation of the process LCA.

4.3 Concrete Frame Multi-Story Residential Building

The result range runs from less than 100 kg/m² to over 1 ton, as shown in Figure 1. There are partial scope differences, for example just the frame taken into account vs. close to all materials, but also important assessment differences. Only one IO LCA was found for this comparison, but it has resulted in by far the highest estimate. With hybrid LCAs the varying amount of IO and process data make the comparisons difficult from this perspective. In the lowest end the low estimates are at least partially the product of adopted assumptions regarding recycling and carbon uptake, which often are not considered. The cut-off criteria varies significantly as well between the studies. According to the LCA tradition, it is typically claimed that only materials with minor impact are excluded, but as discussed by Suh et al. (2004) and depicted by Heinonen et al. (2016), these excluded shares can easily be heavily underestimated. Thus scope-wise a more complete assessment can lead to substantially higher estimates even when the assessments would otherwise be similar. Further differences, outside of those caused by the actual building

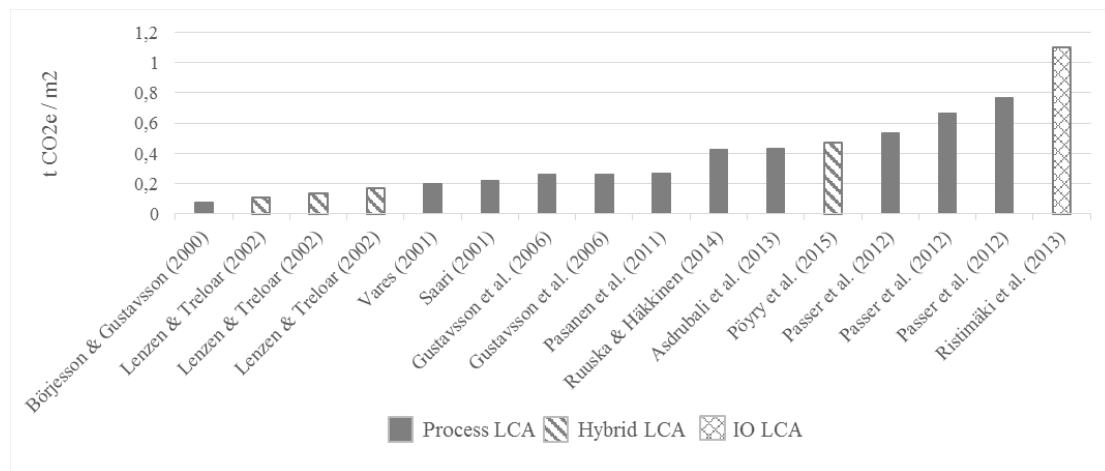


Figure 1. Results per m² of the selected 16 cases.

qualities, can result simply from the assessment database choice, as depicted recently by Herrmann and Moltesen (2015).

5. Discussion

The aim of this paper was to study the reliability of environmental assessments in the built environment. The scope was further limited to GHGs and the LCA method, but it is very likely that a similar situation exists with regard to other impact categories and assessment techniques as well, as discussed previously by Heinonen et al. (2015). Three cases were presented to depict and discuss some problematic issues: (1) a 1.2x1.9 m wooden frame window, (2) a steel-body passenger elevator, and (3) a multi-story concrete frame residential building. Through each example different uncertainties were discussed.

The errors and uncertainties of LCAs have been studied for a long time (e.g. Lenzen 2000; Huijbregts 1998 a, b), but not many studies exist which have concentrated on the built environment. Lenzen and Treloar (2002) suggest that the truncation error can potentially be of the magnitude of 50% in building LCAs, but not many other such direct method comparisons or uncertainty analyses exist. Actually many studies report the results as if they were precise and not subject to uncertainty. While this study is very limited in scope and its ability to give evidence, it brings up issues which should be better taken into account and studied more in the future.

Overall it seems that there is room and need for development to make LCAs more robust in the context of the built environment. This is not to say that current assessments are worthless, but anybody reporting an LCA study or utilizing the results for decision-making should understand the method well enough not to draw wrong conclusions. For example, the cut-off impacts from the assessment boundary selection may well be underestimated, the different inherent errors make it difficult to compare the results of process LCAs and IO LCAs, and “first tier truncation” can be a severe problem, though currently not well recognized at all. It is striking how much an assessment with just the main materials included seems to underestimate the actual emissions, or how different is the outcome for an assessment of the same object but using a different LCA method. Furthermore, several other assessment assumptions can vary between two studies and cause the results to be very different, even for similar assessment objects, as was discussed with regard to the residential building cases in Section 4.3.

6. Conclusions

Based on this study, it seems obvious that there is plenty of room for development of LCA methods in the context of the built environment. Currently the assessments vary so much that the results are often not comparable between different studies without a deep understanding of the methods and the details of the studies. The study did not reveal particularly new issues, but surprisingly little attention has been devoted to the uncertainties presented, especially given the order of magnitude this study (and previous studies) indicates. The “first tier truncation error”, meaning the last production phase being excluded when such objects are assessed which utilize prefabricated products, such as windows or pipes in building construction, has received very little attention in general. However, this error exists particularly in such sectors as the built environment, especially with buildings but to some extent with other civil structures as well. At least this study suggests that it can be a significant source of bias. Finally, this study only shows areas where more work should take place, though the message is still important and the development of needs is significant and urgent.

Acknowledgment

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Establishment Of Weights In A Rating System Of Sustainable Housing In Colombia Through The Analytic Hierarchy Process (AHP)

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Abstract

Currently there are several rating systems or certifications systems for sustainable construction in the world such as LEED and BREEAM. These responds to a need for generating solutions to the big problems that construction involved: emission of greenhouse gases, energy consumption, waste generation, water and materials consumption.

In this order, these certifications systems are typically formed as checklists required to obtain a minimum number of points according to established evaluation guidelines and generally associated with certain categories of impact.

In the other hand, we have that Decision Theory provides a methodology called Analytic Hierarchy Process, which consist of a process of ranking criteria from the implementation of a matrix of pairwise comparison.

In this way, this study proposed to use the AHP methodology for the establishment of weights in an eventual rating system of sustainable housing in Colombia, according to its context and the kind of current information and tools at legal level that the country has. The above, considering that Colombia does not have a clear regulatory scheme for sustainable buildings yet. Therefore, this study seeks to provide a strategic tool for the regulatory framework for sustainable housing in Colombia from the integration of the Decision Theory with existing certification systems adapted to the country. All that, with a panel of experts with people from academia and industry.

As a result, the study shows how this proposed strategy can be helpful in countries which do not have sufficient technical tools to generate robust impact assessment schemes, as LEED in the United States. Thus, it can be obtained very good results from a consensus between academia and industry in Colombia, which are comparable with recognized certification systems in the world.

Keywords: Sustainable Housing, Analytic Hierarchy Process (AHP), Weights, Certification System, LEED.

1. Introduction

According to the definition of Sustainable Development from the Brundtland Report in 1987, it is important to consider the great contribution that construction industry can give to this concept because of its impact to the environment: consumption about 40% of the world's electricity, 17% water, 25% of felled timber, and production over 40% of overall waste and 33% of carbon emissions (Thakore, Jack, & Benuzh, 2013). Moreover, in the specific case of this research it will be important considering that cities in the world are composed around 70-80% by the residential sector.

In this way, nowadays it exists in the world classification and certification systems for sustainable buildings seeking to assess the presence of factors related to environmental quality in the different stages of the life cycle of a building. Although each of the certification systems is an approach or own philosophy, depending on where it has been conceived, all options provide design/construction that are environmentally responsible, and in turn deliver awards and public recognition to the additional effort required to conduct more sustainable projects (Secretarías Distritales de Ambiente, Habítat y Planeación de Bogotá, 2014).

In Colombia, recent governments have shown in one way or another some interest in the topic, however, it has not yet been given a broad and comprehensive policy for the country that offers some kind of official certification system that promotes sustainable construction.

Therefore, and in order to provide tools to facilitate and coordinate with the items that the country already have in terms of public policy aimed at promoting sustainable construction, the following study presents the research done for the generation of a first Referential of Sustainable Housing in Colombia (or certification system for the housing sector) and the establishment of the weights of their criteria, after the implementation of the Analytic Hierarchy Process methodology as a tool for decision making level.

2. Background

In this section we will understand briefly the determination of weights in the two main certification systems in the world (LEED and BREEAM) and the Analytic Hierarchy Process implemented in this study.

2.1 Leadership in Energy and Environmental Design (LEED)

Taking into account that LEED scheme is organized in categories and credits, it is important to understand that the process to be followed for this certification is basically to achieve a certain score from obtaining some criteria, known as credits within the system, which seek to meet the needs of sustainable development. These credits, according to the impacts they want to avoid, minimize or mitigate are classified into the following categories: Integrative process, Location & Transportation, Sustainable sites, Water efficiency, Energy & atmosphere, Material & resources, Indoor environmental quality, Innovation, and Regional priority.

In the previous version v3 credits' weights were determined by impact categories by TRACI software. For the current version v4 new impact categories were used.

For the current version v4 they coupled to the premise of making "greatest positive impact" and not "do less harm", for which the TRACI categories did not fit totally into their new goals. This was based on the fundament that categories did not capture totally sustainability goals anymore and they were not the best way to make a life cycle assessment for all components that a building has.

The above idea led to the United States Green Building Council (USGBC) to favor the creation of their own impact categories to broaden their approach to social, environmental and economic material. This made the certification stop focusing on how "environmental problems can be reduced", but in what LEED certified projects should contribute and achieve.

In this way the USGBC devised the form to work with impact categories and subcategories with which every credit was scoring. They basically did an exercise of association between credits and subcategories. This exercise had three aspects (duration, control and relative effectiveness) which were multiplied in a formula and in that way it was obtain the score of the credit. The score resulting from the association of each credit with all subcategories was computed and dictated the final score for each credit (Klaw, 2013).

2.2 Building Research Establishment Environmental Assessment Methodology (BREEAM)

Although this system does not name as "credits" the criteria they use within their categories, they have some similarity with LEED in their overall scheme. In that way, we can see they have the following categories for the assessment: Management, Energy, Health & wellbeing, Transport, Water, Materials, Waste, Land use and ecology, Innovation, and Pollution.

BREEAM uses a scoring system explicitly derived from a combination of weights and classifications product of a consensus by a panel of experts. The results of this exercise are used to determine the relative value of the environmental sections used in BREEAM and its contribution to the overall score of this Certification Scheme.

This scoring system is defined in detail in the BRE Global Core Process Standard (BES 5301) and in the documents that support its proceedings, which are part of the Standard BREEAM and Code for a Sustainable Built Environment. The classification of impacts used in BREEAM follows the same mechanisms score of BRE Green Guide to Specification and BRE Environmental Profiling Method for building materials. BREEAM FCO provides ways to adapt this system in specific credit score by region or country in which a project is certified (BREEAM, 2011).

2.3 Analytic Hierarchy Process (AHP)

It is a method that allows represents a problem using a hierarchical structure where the last link are alternative decisions. This method was developed in the 70s by Thomas L. Saaty and since there it has

been studied extensively, currently it is being used in decision-making in complex scenarios, where people work together to make decisions when human perceptions, judgments and consequences have a long-term impact (Bhushan, 2004).

The application of AHP begins with a problem to be decomposed into a hierarchy of criteria in order to be easier to analyze and compare independently (See Figure 1). After this logical hierarchy is built, the decision makers can systematically evaluate alternatives when making comparisons between pairs for each of the criteria. This comparison can use the specifics of alternatives or human trials as a form of input information underlying (Saaty, 2008).

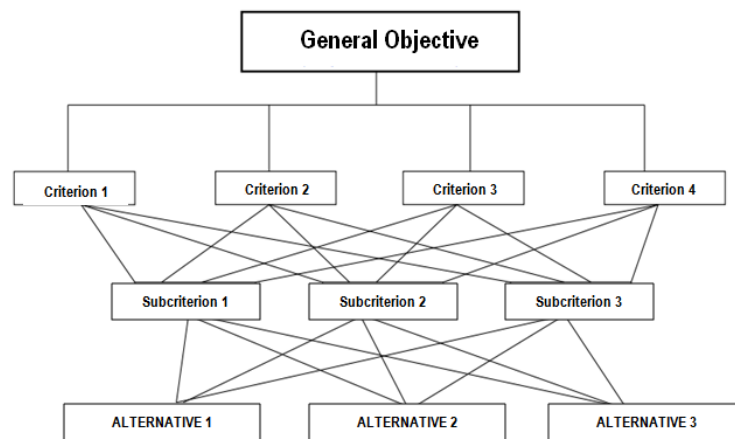


Figure 1: Example Hierarchical Structure

After the definition of the hierarchical structure, it is necessary to construct matrices. In this manner, using an appropriate scale, it should be performed pairwise comparison for each of the elements of each level in relation to the elements of the next higher level (Saaty T. L., 1994).

Then, using an estimation method, the relative weights for each element are calculated with respect to the other elements and at the next higher level. After obtaining the weights of each element, the weight of each of the alternatives is estimated and sorted. It is important in this point to understand the estimation method proposed by Saaty, which mainly part of the matrix principle of $A * W = \lambda_{m\acute{a}x} * W$ where A is a matrix with a dimension n , $\lambda_{m\acute{a}x}$ is the maximum eigenvalue of matrix A , and W is the final weight vector estimated appropriately normalized so that its components sum to 1 (Castillo, 2006). Theory behind the above can be revised in the literature.

Finally, a proper interpretation of the results projected by the model is done. Once interpreted the consistency of the results is analyzed and determines whether changes are needed to the model. Once it reaches a satisfactory answer, the right choice is determined.

3. Methodology

For the development to this study it is important to understand that first we had to limit the scope of this. In that way, although the present study was focused on generating a first Referential for

Sustainable Housing in cities of cold zone (see Table 1), this research despite assist in the establishment of categories and credits to be considered in this first version of the certification system, with the support of the Colombian Sustainable Building Council (CCCS), it was concentrated mainly in the establishment of the ID, Name, Objective and Weight of each of the credits to be considered in the Referential, but we did not work in their requirements, form of implementation, calculations, Regional Variation and References.

Table 1: Climatic zoning for the application of environmental criteria proposed by the Ministry of Environment, Housing and Territorial Development in Colombia

Warm zone – Wet	Warm zone – Dry
Altitude in the range of 0 to 800 meters above sea level, temperatures above 24 ° C and relative humidity above 75%	Altitude between 0 and 800 meters above sea level, with greater than 24 ° C temperatures and relative humidity below 75%
Temperate zone	Cold zone
Altitude in the range of 800 to 1,800 meters above sea level, mean annual temperature between 18 ° and 24 ° C and relative humidity between 70 and 85%	Altitude above 1,800 meters above sea level, temperature between 12 and 17 ° C and relative humidity between 60 and 80%

Additionally, it was considered appropriate to restrict climatically (cold zone) and typologically (new multifamily housing projects) the exercise given the geographical and urban conditions that are assumed can get to induce significant differences in generating a specific system of certification for housing, according to some discussions on the subject (Buendía López, 2013). Thus, this study, in addition to taking the initiative to generate a first version of a certification system that provides the theme of sustainability in the country, it leaves the door open for future research in different areas and different types of housing buildings to validate if the course assumed is correct or it could eventually generates a single Referential of Sustainable Housing for all Colombia.

Thus, after understanding the problem that we wanted to address - definition of credits that should be considered for a first version of a certification system for multifamily housing in cold areas of the country and the determination of its possible weights - It began with the selection of candidates, either for their expertise in environmental issues and/or their sustainability or outstanding professional preparation, for being considered as experts on these issues to participate in the development of this exercise. This group was mainly composed of professors from the University of the Andes and professionals from member companies of the CCCS.

From this, several meetings was agreed with experts who voluntarily wanted to participate in this study. The first meetings focused on establishing what the AHP methodology termed as criteria and subcriteria, which for purposes of this research are the same categories and credits respectively. For this phase, it was decided to begin the exercise taking into account the schemes of LEED Homes v4 from United States and the Reference House from Brazil, thus experts gave feedback on what they saw relevant or not to the Colombia case, as well as some criteria were not being taken into account and that experts considered they should be included. At this point, it is important to understand the modification

done to the AHP methodology, because in this case we did not have alternatives, just criterion (or categories) and subcriterion (credits), this, using the same LEED terminology (see Figure 2).

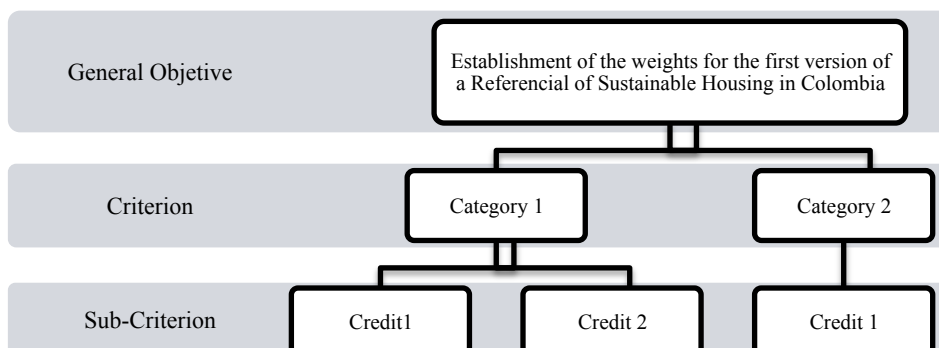


Figure 2: Structuring of the problem

Later, when all the information was gathered and some preliminary credits were established, we proceeded to the elaboration of the matrices according to the scale of Saaty¹, which was done using the software *ExpertChoice*, program that allowed evaluating immediately the index inconsistency of matrices, thereby reducing the error which would be evaluated later.

Although ideally suited for this type of methodology is the generation of a panel of experts, which all interact to finally define a single matrix, given the difficulty appeared to gather all participants in one place, due to the agenda that most of them handled, we decided to averaging matrices with a geometric mean, according to the suggestions of Professor Mario Castillo, an expert in AHP issues in the Industrial Engineering Department of the University of the Andes, to finally get results in terms of the score for each of the categories and credits considered.

4. Results

According to the methodology explained above, we finally had six matrices in agreement with the Table 2.

Table 2: Participants in each of the considered matrices

	Assessed Level	Number of participants
Criterion	1.General Scheme – All the categories	6
Subcriterion	2.Implantation	5
	3.Efficient use of water	7
	4.Energy & Atmosphere	8
	5.Material & Resources	7
	6. Indoor Environmental Quality	7

¹ Saaty scale has a range between 1/9 and 9 where 1/9 means that the criterion compared with another one is extremely not important and 9 when the criterion is extremely important compared with the other one

The following Table shows the specific results in every final matrix obtained after the geometric mean applied to the several matrices for each level handled.

Table 3: Results of the weights obtained from the every considered case

Assessed Level	Matrix A	Vector W (Weights)																																																																																																																																													
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The following is the final Referential obtained, as previously it was explained:

Table 4: Final Referential of Sustainable Housing in Colombia

REFERENTIAL OF SUSTAINABLE HOUSING IN COLOMBIA			
FIRST VERSION		100 Possible Points	
IMPLANTATION		Possible Points	32
IMP CR1	Control of negative impacts by altering the field	4	
IMP CR2	Project orientation based on the solar chart	6	
IMP CR3	No use of invasive plants	2	
IMP CR4	Site Selection	3	
IMP CR5	Location near existing urban developments	3	
IMP CR6	Access to open space	3	
IMP CR7	Reducing the heat island effect	2	
IMP CR8	Stormwater management	4	
IMP CR9	Toxic products and plague control	1	
IMP CR10	Compact developments	4	
EFFICIENT USE OF WATER		Possible Points	16
UEA CR1	Efficient water use indoors	10	
UEA CR2	Efficient water use outdoors	3	
UEA CR3	Measurement and control of water consumption	3	
ENERGY&ATMÓSPHER		Possible Points	22
EYA CR1	Quality of electrical installations of low voltage	3	
EYA CR2	Energy efficiency of hot water system	2	
EYA CR3	Artificial lighting	4	
EYA CR4	Energy efficiency of the residence	5	
EYA CR5	Efficient home appliances	2	
EYA CR6	Generation of electricity through renewable energy	2	
EYA CR7	Energy audit of installed systems	2	
EYA CR8	Sectioned measurement and verification	2	
MATERIAL&RESORUCES		Possible Points	9
MYR CR1	Management plan for construction waste	2	
MYR CR2	Waste management plan for the operation of the project	2	
MYR CR3	Environmentally sustainable products	3	
MYR CR4	Products and materials with improved components	2	
INDOOR ENVIRONMENTAL QUALITY		Possible Points	21
CAI CR1	Control of flue gas emissions	4	
CAI CR2	Ventilation	4	
CAI CR3	Outdoor air filtration	2	
CAI CR4	Comfort of the indoor environment	2	
CAI CR5	Control of particulate pollutants	2	
CAI CR6	Protection from garajes pollutants	3	
CAI CR7	Noise protection	1	
CAI CR8	Cigarette smoke control	3	
CERTIFIED		40-49	
SILVER		50-59	
GOLD		60-79	
PLATINUM		80+ Points	

5. Discussion

We did a whole analyses from the results in every matrix considered with the different experts' opinions, however, below only we will present the analysis made for the matrix of the general scheme case.

For the general case, which determines the weight or importance of each of the categories previously exposed, it looks like at the end of the procedure performed, on average the categories were organized

from highest to lowest score as follows: Implementation, Energy & atmosphere, Indoor environmental quality, Efficient water use and Materials & Resources

Now, in Figure 3 we make a comparison of the results obtained for the Colombian case with the scheme in USA (LEED) and Brazil (Referential House) in terms of possible points within the certification systems. Thus, it is important to note, and although it was mentioned that while the whole exercise was done with relative weights with a base of 1, then the corresponding extrapolation was made to a system that considers 100 possible points.

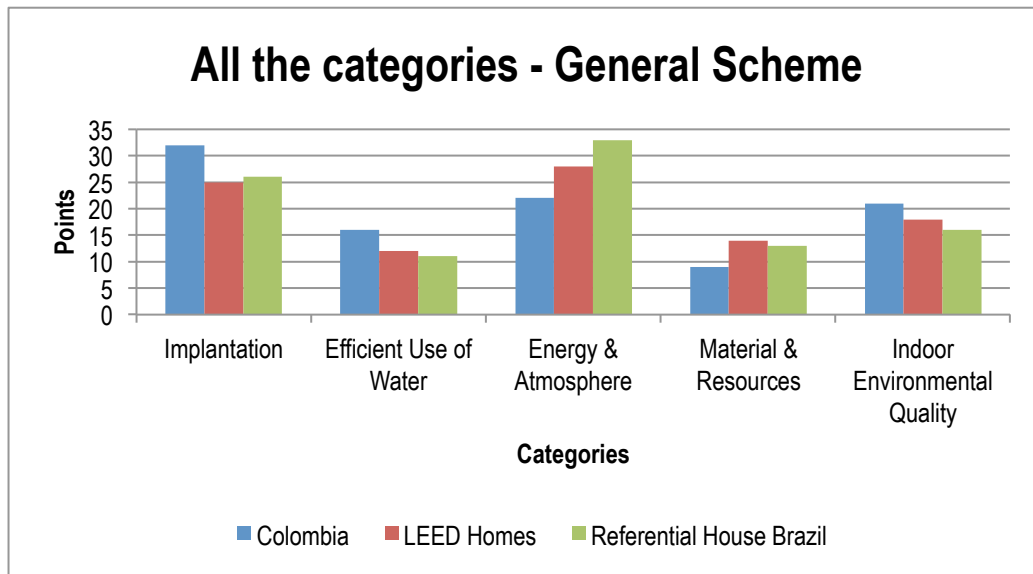


Figure 3: Comparison between categories of rating systems from Colombia, USA and Brazil

In that way, when we compare with the Referential House from Brazil and with LEED Homes from US, we can see in Colombia the most important category is Implantation, while for the others two countries is Energy & Atmosphere. For LEED, this can respond to the way of energy production in the country, linked directly with the emission of greenhouse gasses, one of the most important themes when we think about sustainability, while in Colombia this happens mainly through hydroelectric, related to water and biodiversity problems (Buendía López, 2013).

Likewise, this difference can be attributed in one or another way to the level of development in Colombia, because it exists a proportional direct relation of this with the energetic consumption, this for example in average the number of home appliances in Colombia is fewer than in USA and Brazil.

Taking into account that each of the systems certification represents an approach or own philosophy, depending on where it has been conceived, it can be seen how in Colombia the most relevant category is that which evaluates overall the place where the project is going to be develop, whose characteristics site promote pollution minimization and optimization of some work situations that facilitate the implementation of sustainable criteria. This is closely related to the planning and management of projects, one of the major problems in the country by the lack of practice of what is known today as *Systems Thinking* and *Integrative Processes*.

On the other hand, it is not surprising that the category with the fewest points have been the Materials & Resources, as well as being one of with less credits considered, because it has criteria that in the

country are not very easy to achieve such as life-cycle assessment of materials, promotion of products whose ingredients are inventoried using an accepted methodology and the use of verified products that minimize the use and generation of hazardous substances. However, this does not diminish the importance of the category, because despite being the one with less points, it has few credits, which obtained a distribution of points similar to other categories. Similarly, this applies to the category of Efficient water use, which is the second to have less points globally, however, by having only 3 credits, they are those with most points when they are compared to other credits, even it is in this category where we have the credit with more weight (efficient water use indoors with 10 possible points). In this sense, it is important to note how in Colombia, despite being potency in water resources, there already is a concern to protect this resource since now.

Finally, we can say that the categories of Energy & Atmosphere and Indoor environmental quality, positioned as the second most important with similar weights, after Implantation, they are those that promote technical developments and some practical modeling of processes that are not widely used in Colombia, which are transcendental in driving the sustainable construction industry in the country. Similarly, these are credits that are undeniably connected with the promotion of high quality in the habitability of the spaces, a fact that undoubtedly affects different areas and dimensions of development and progress of the people.

6. Conclusions

According to the whole research here exposed, in this section we will describe some conclusions about the implemented methodology, the obtained results and some challenges that this study can deal:

- To have AHP as a strategy for the solution to the problem posed was an effective mechanism, because it allowed the structuration of this one under a multicriteria landscape, following a paradigm related to broad rationality, flexibility and realistic approaches compared to the traditional paradigm, in this way this allowed the incorporation of the human factor (integration of the tangible and intangible) in the search of the “best” solution to the problem (Moreno, 2002), we arrived to a Referential of Sustainable Housing according of Colombia’s needs, despite the complexity of the situation. Above, taking into account also the lack of technical tools that the country still has to develop other mechanisms for the determination of the weights in this kind of certification system.

- We can say the geometric mean represents very well the most of the experts’ opinions without the perturbation of the sample by extreme values. In the same way, although it was thought the panel of experts was ideal according the traditional AHP, we saw the methodology implemented by us, geometric mean, was adequate because of the possible partiality of experts in a table, while our methodology reached a balance between experts opinions. All the final obtained matrices were under 2% of inconsistency, which increase the reliability of results that in terms of Analytics or Theory of Decision allows to make decisions more easily.

- It is important to understand that this first exercise seeks to be an approximation to what a Colombian system certification of sustainable housing should be in the country. In this way, there should be more investigation about this topic that complement or change what we found, if these kind of things mean a real support for this research. In that sense, it will be necessary to work in the

requisites, form of implementation, calculations, regional variations and references of the credits that we did not do in this first phase.

- Nowadays, although the entire advance the world has reached about sustainable techniques in construction industry, as the certification systems, there are things in which we have to work harder as a developing country like culture, education and awareness of the crowds, who are the final operators of the sustainable buildings. Thus, the really important thing is that certification system are responsible and search real sustainable projects more than senseless recognition, as it has been saw in some cases around the world.

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COMPLEX INTEGRATED APPROACH OF SUSTAINABLE ARCHITECTURE Based on Properly Modifiable Site Specific Database

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Abstract

Preserving our environment has come to the forefront of our society's concerns and architects may not be indifferent. Widespread awareness of climate and other environmental change together with huge amount of the technical opportunities have triggered professional demands for architects with advanced skills. According to the new aspects and tools, the architectural design process must become more conscious. Our main task is not only to create new technical variations, but to re-define the design process taking into consideration the whole complexity of available information and data, while providing permanent control over the decisions. Design process plays a very important role in architecture, not just aesthetically, but technically as well.

Careful consideration of surrounding conditions from the earliest stage of the design process can have an enormous impact on reducing subsequent operating costs and protecting our nature. All over the world there are specific traditional solutions relating to climate in order to utilize the natural conditions for the benefit of human comfort. These traditions help us to develop really sustainable decisions in contemporary architecture.

Efficiency of design process depends on the adequacy of the data applied. Systematization and integration of all relevant information and aspects into creative design process is a crucial part of contemporary architecture. We should re-think architectural design process as a coordinated set of stages and sub-stages replacing traditional experience-related process by a more rational, and theory based approach of choices and solutions for specific design problems. There is a need for developing a systematic structural and material selection system that will enable architects to identify relevant criterias effectively and to evaluate the options accurately. Analysis of impacts, requirements, and structural performances at each design stages can be the common approach in the dialogue between architects and experts. Preventive and remedial measures should always be evaluated in the context of the whole by holistic method.

The Holistic Performance Based design method responds to surroundings by continuously fitted, properly modifiable Multilevel Project-oriented Site-specific Database. This system integrates skills, knowledge and tools of “passive” and “high-tech” design elements into a more conscious complex design process.

Keywords: Holistic, Performance-Based, Project-oriented, Site-specific, Database

1. Introduction – built environment: comfort and pollution

Shelter and comfort are the basic needs for all human beings no matter where they live. We want a comfortable place to protect us against heat/cold, humidity, environmental diseases, dangerous animals, burglary and other possible threats. We want a comfortable environment where we can live a protected and healthy life. The aim is to create a high level comfortable and stable climate for our everyday existence. Increasing functional requirements all together with growing human population and technical development resulted not only higher level of internal comfort but at the same time environmental pollution and health problems. (Fig. 1.)



Figure 1 [20, 21] *Dream and reality of built environment*

“Building design and construction use significant quantities of natural resources and materials. The building industry consumes 3 billion tons of raw materials annually -- 40 percent of the total material flow in the global economy. The manufacturing process of new materials is water and energy intensive and contributes to environmental degradation and pollution. Harvesting, extraction, mining, and processing new materials pollute the air and rivers and threat ecosystems and wildlife. North America, Europe and Japan consume more than 25 percent of the world's annual 4.5 billion cubic meters of wood production. According to the Natural Resource Defense Council (NRDC) [22] at present rates of destruction the rainforests will be gone by 2050. In addition, global wood production is expected to double over the next 30 years. Consumption of other raw materials and natural resources continue to accelerate.” [23]

“The Building Sector is responsible for almost half of the energy consumption (49%) and greenhouse gas (GHG) emissions (47%) in the U.S. [24] The sector is expanding, which is bound to increase its energy consumption as it is declared in “Directive 2010/31/EU [25] of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings”. While the majority of the energy consumption, and their associated emissions, come from building operations (such as heating, cooling, and lighting), the embodied energy and emissions of building materials and products are also becoming increasingly significant. A very small amount of energy-efficiency improvement on this field could lead to significant economic savings. A building’s “energetic DNA” is hard-coded in the architectural concept. The possible deficiencies of architectural design decisions can be balanced only by costly engineering solutions.

Therefore, reduction of energy consumption and the use of energy from renewable sources in the buildings sector constitute important measures needed to reduce energy dependency and greenhouse gas emission. If we do not reduce GHG emissions, we risk triggering dangerous climate change, resource depletion, acidification, and eutrophication. The latest International Panel on Climate Change (IPCC) Fifth Assessment Report [26] confirms the necessity for immediate and sustained action on climate change, detailing how close we are to a turning point in the earth’s climate system. The underlying conclusion of the report is that the time has arrived for taking the necessary steps to preserve liveable conditions on earth. As quickly as possible, we must stop burning fossil fuels, aiming for a complete phase-out by around 2050.

And the products we select affect the quality of the spaces we inhabit. People spend appr. 90% of their time indoors in USA, and the quality of air in buildings has been proven to have significant negative health impacts on them. The indoor environment is not only a health and comfort issue. It also affects work performance and learning skills of the occupants. Many new buildings have proven to be physiologically uncomfortable and unhealthy as well. Several people, who live and work in

modern houses, have complained of periodical symptoms of malaise (headache, fatigues, drowsiness, irritation in eyes and nose, dry throat, non-concentration, nausea and allergic symptoms). The choice of materials, constructions can improve or degrade our indoor air quality and we can affect that quality through the materials and products we select. (Fig. 2.)



Figure 2 [27] Polluted environment

Preserving our environment has come to the forefront of our society's concerns and architects may not be indifferent. Widespread awareness of climate and other environmental change (decreasing natural resources, pollution of environment) together with huge amount of the technical opportunities have triggered professional demands for architects with advanced skills. The successful integration of complex principles and new technologies into a creative design process in practice and education has proven elusive. [1]

In view of these environmental concerns, sustainable design embodies the following goals:

- Minimize consumption and depletion of material resources.
- Minimize the life-cycle impact of materials on the environment.
- Minimize the impact of materials on indoor environmental quality. “[28]

The basic question is how to create a really sustainable built environment to protect our natural surroundings and at the same time to provide comfortable, healthy life for people? Should we use more high-tech solutions or try to follow the passive adaptive design concept? How to find the balance and the best options?

2. Sustainability: adaptation vs. high-tech application

There is a close connection between the way we build our houses and the surrounding climate. Climate (sunshine, temperature and wind) has a crucial influence on all parameters of building such as orientation, glazing, thermal mass, insulation, ventilation and zoning. Fundamentally functional arrangement and construction of the house are to set the framework for indoor climate which is different from the outdoor climate. All over the world there were specific ways of relating to the climate. Whatever the general climate is - cold, hot, temperate, dry or humid - houses were built so that the local conditions are being utilized to a maximum. Most old cultures had a good knowledge of the local resources (climate, materials) and understood how to utilize it instead of working against it. People traditionally built their houses by hand out of local natural materials (stone, timber, grasses, burned clay etc.). Building types and constructions were developed for centuries, so they had time to have experiences how to create building shape, functional arrangement, to choose materials responding on their surroundings. Porch in front of the rooms provides shading in hot summer and sufficient lighting in winter, walls made of pise or solid clay brick had high thermal mass according to the temperate climate. (Fig. 3.)



Figure 3 [29] Traditional built example in the temperate zone (Hungary)

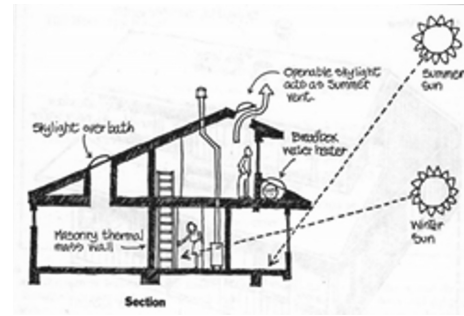
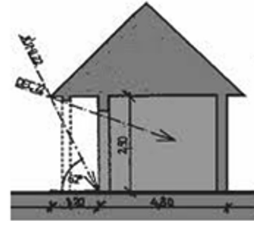


Figure 4 [31] Passive solar design

The environmental impact of ancient houses was slight. Living houses, until cc. the end of 20. Century, were mostly adaptive without crucial environmental impact. Experiences of traditions can be useful today as well. So called “passive architectural design system” [30] follows this way and relies on natural principles instead of mechanical systems to provide a non-polluting source for internal comfort. (Fig. 4.) Whether could we eliminate industrial products in our houses by this passive design method?

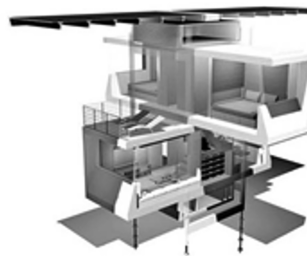


Figure 5 [32] Most of the modern houses consist of artificial materials and high-tech applications

Development of society and industrialization has resulted with us starting to move away from the individual houses and to begin building uniform and anonymous houses located close to factories. In the course of time, these houses have spread from the centre of the city to its enormous suburbs. Each individual, therefore, no longer has influence or understanding on the relation between their house and its external environment. In globalized market the building materials can be achieved almost from all over the world and we use a huge amount of artificial structures created by industry. (Fig. 5.) The required high level internal comfort is granted by mechanical equipment, e.g. HVAC systems and regulated mainly by high-tech solutions. Houses are centrally heated, air-conditioned and the location of the house in relation to the natural conditions is not that important any more. Buildings’ functional arrangement, shape, materials are hardly determined by natural surroundings, but by industrial products, technical and economical possibilities.

Buildings today are complex concatenations of structures, systems and technology allowing modern-day building owners to select lighting, security, heating, ventilation, and air conditioning systems independently (“smart buildings”). “Smart building is about living in a machine that cares about you” [33]. (Fig. 6.) Recent advances in data gathering and analysis are opening up new possibilities for smart building management systems (BMS) -saving energy through targeted supply. Sensors are increasingly being installed in buildings to gather data about movement, heat, light and use of space. Such information may ultimately be incorporated into real-time Building Information Modelling (BIM), enabling live data to be held in the data structures used to describe building design. The lifespan of a building is currently around 50 to 100 years, while digital technology changes over a dramatically shorter two- or five year cycle. The “smart” buildings should be created as a core infrastructure into technical “applications” can be plugged. The vision of the future buildings *connect* the various pieces in an integrated, dynamic and functional way is that building seamlessly fulfils its mission while minimizing energy cost, supporting a robust electric grid and mitigating environmental impact.” [34] Whether is it enough for sustainability?

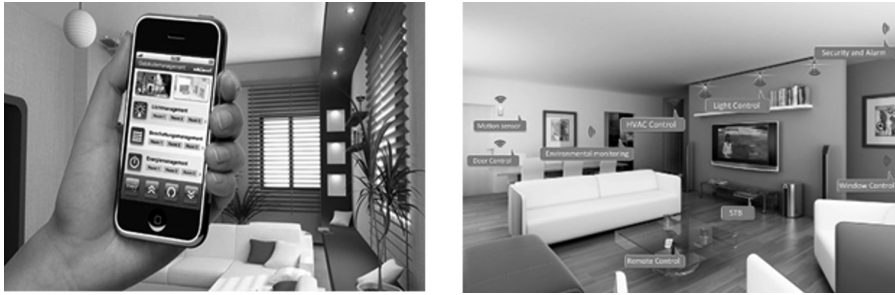


Figure 6 [34] Mechanical control of internal comfort

Last period something surprising has been recognized about many so-called “sustainable” buildings. When actually measured in post-occupancy assessments, they’ve proven far less sustainable than their proponents have claimed. In some cases they’ve actually performed worse than much older buildings, with no such claims. A 2009 New York Times article, “Some buildings not living up to green label,” [2] documented the extensive problems with many sustainability icons. Systems may appear to be well engineered within their original defined parameters — but they will inevitably interact with many other systems, often in an unpredictable and non-linear way.

That means we should look towards a more complex design methodology, combining diverse approaches, working across many scales, and ensuring fine-grained adaptivity of design elements. We have to integrate skills and knowledge of “passive” and “smart” design elements into a more conscious comprehensive design process.

3. Consequences of technical integration

Design in contemporary architecture has become a lot more exploratory in recent years. Digital architecture and huge amount of construction products allows a diverse range of complex forms to be created. As technology evolves and software becomes more powerful, it enables architects to explore new possibilities. Introducing 3D software into the architectural design process has allowed contemporary architects to explore new depths and push design boundaries. The huge number of Information Technology Building Industry products (CAD etc.) gives architects the feeling that almost any geometrical shape may be physically realized. Consequentially, professionals envision increasingly unusual building types. (Fig. 7.) Houses are more often than not, too complicated and too expensive.



Figure 7 [20] Vision of a future city and built heritage of Budapest

Every building project involves the choice of building materials. Recently, we have thousands of new artificial materials and structures sold all over the world while the functions of our buildings have been changed and expanded. Selecting suitable building material options is a very complex process, being influenced and determined by numerous preconditions, decisions, and considerations. Likewise, multiple factors (cultural, economic, ecological etc.) should be often considered by the architect when evaluating the various categories of building materials. As a result, these sets of factors or variables often present trade-offs that make the decision process even more complex. Cautious

consideration of contextual preconditions is crucial to defining appropriate building materials or products.

Database is the basic component of contemporary engineering calculation. The database information can be labelled according to data content, type of data affiliated in a computer program, the targeted group of stakeholders etc. Earlier database was an experience based system. Each stakeholders added their knowledge and information into the project. Elements of database were visible and accessible in documentations, maps, catalogues etc.

As part of globalization the building elements - materials and components - are arranged on internet through some product oriented building element basis. Clients may select structures and materials as they compile their specification. These extensive catalogues are continually being updated with specifications covering most common products. It seems to be used easily and quickly, but architects have some difficulties in choosing the best product from these databases because of the huge amount of elements (one database division – e.g. thermal and moisture protection - could contain more than 10 000 enterprises and their products!). (Fig. 8.) Comparison the data of several products sometimes is problematic because of the different background (standards, measurement methods, units etc.). In these databases there is no information on application of structures and materials according to the local conditions.



Figure 8 [35] Product oriented architectural database

The computer database programs through Database Management Systems (DBMSs) are a ubiquitous and critical component of modern computing. [3] A typical DBMSs needs to be compatible with many different connectivity protocols used by various client drivers. Computer Models can be created in 3D, and manufactured directly from the 3D data. Computer modelling programs rely on "sets of numbers stored in electromagnetic format. The computer database architecture is the set of specifications, rules, and processes that dictate how data is stored in a database and how data is accessed by components of a system. The digital database architecture includes data types, relationships, and naming conventions, describes the organization of all database objects and how they work together. This knowledge is implemented during the selection, designing and inspection of materials and construction components. The structure of computer databases is hidden, the architect can use it through the Dialogue Boxes, windows. (Fig. 9.) The storage and access of these data depend on the computer program so these are available only for those clients who have the appropriate software. These databases require the high level awareness of applied parameters and suitable computer program.

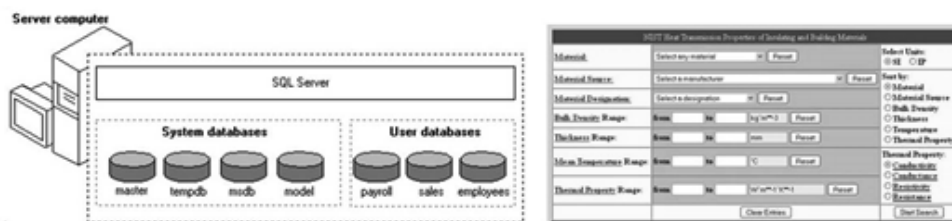


Figure 9 [36.] Computer Database Management Systems

Computer Analysis and simulation programs modelling environmental, technical and economic forces in order to quantify performance and enables us to analyse multiple design options.

Computer Aided Design systems (CAD) make the construction and drawing of building plans rapid and accurate. Projected physical dimensions and surfaces may be changed very easily. Architects – in theory - could have more control over the building design process, based on “freedom” of shaping, modification through computer modelling, simulation methods of reality. This technique does seem to be very accurate, but sometimes it can be difficult to recognize relation in between several calculation methods and parameters. Separated simulation computer algorithms sometimes result with reductionism (reductionism in science says that a complex system can be explained by *reduction* to its fundamental parts) replacing the holistic ("The whole is different from the sum of its parts" [37]) approach, because measures of building construction are separated in independent processes and complex, comparative analysis of requirements and product performances in the context of the whole is missing. (Fig. 10.) It can be sometimes problematic because of interaction in between of several parameters.

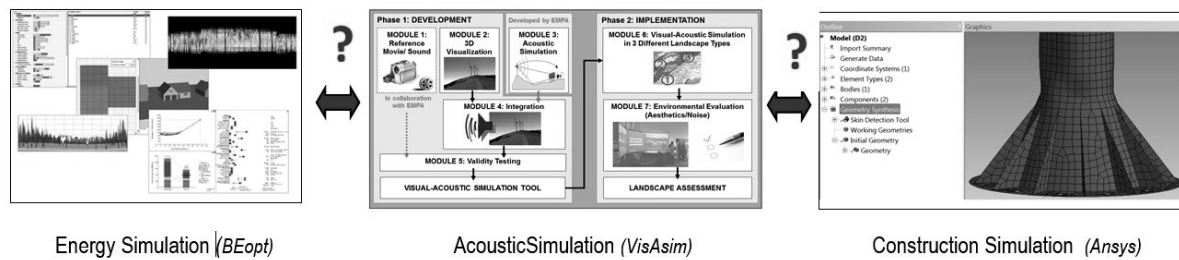


Figure 10. Computer simulation programs

4. Conclusions

According to the new aspects and tools, the architectural design process must become more conscious. Recently our main task is not only to create new technical variations, but to re-define a really conscious, continuously step by step controlled design process taking into consideration whole complexity of all available social, cultural, functional, economic, natural, structural, material and technological data, while providing permanent holistic control over the decisions. Design plays a very important role in architecture, not just aesthetically, but technically as well.

Careful consideration of surrounding impacts (climate: sunshine, temperature and wind, soil mechanics etc.) from the earliest stage of the design process can have an enormous impact on reducing subsequent operating costs and protecting our nature. The way we build should be in dialogue and reflect with local conditions instead of working against the surrounding nature. Traditional architecture relating to the climate utilizes natural conditions for the benefit of human comfort. These traditions could help us to develop really environmental friendly design decisions of contemporary architecture.

Buildings we design should be adapted to its real environment both in shape and structure providing maximum internal comfort and at the same time minimum harmful environmental impact. This seems to suggest that there is a need for developing a systematic structural and material selection system [4, 5] that will enable architects identify and prioritize the relevant criteria to effectively and accurately evaluate the trade-offs between social, technical, environmental, economic and performance issues during the construction evaluation and selection in design process.

Ibuchim Ogunkah and Junli Yang (2012) define material selection of vernacular buildings based on comparative analysis [6]. Their of the collected data pointed out that there are significant changes in building performance across countries, given their differences in building code restriction level in the use and mutual recognition of performance of materials, geographical and environmental conditions. (pp 19) (Fig. 11.) They holistically aim to develop a set of useful knowledge bases and structured ‘selection’ systems that will serve as the basis for evaluating such building materials in terms of their sustainability, during the design process of a building project. This research consists of a suggested toolkit of material selection.

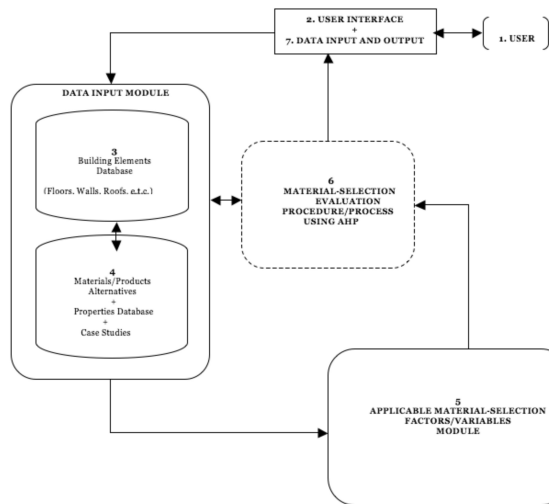


Figure 11 [6] Conceptual Model of material selection toolkit.

Therefore, to enable a structured and more comprehensive approach in the design-decision making process, it is important that the design-decision maker (architect, designer or expert) takes into account several material-selection factors or variables in order to facilitate the processes of comparing and identifying the best material option(s) across different categories. Actually the difference is how the designers interprets, synthesizes, and evaluates the collected data and techniques in their design process as result of all their perceptions, aims, convictions and skills.

Systematization and integration of all relevant information into creative design process is a crucial part of contemporary architecture. By re-thinking the architectural design process as a coordinated set of stages and sub-stages, replacing the traditional experience-related process by a more rational, and theory based approach choices and solutions for specific design problems, traditionally taken base on experience or individual thinking, can be now taken base in complex awareness and attentive to potential alternatives. [7] Preventive and remedial measures and decisions of architectural design process should always be evaluated in the context of the whole. (Fig. 12.) The house should be approached as a complete system, with specific features and performance requirements, not as a collection of independent industrial engineering disciplines (electrical, mechanical, structural, and so on), as an integrated part of a process in dialog with the surroundings and its inhabitants. Holism (from ὅλος *holos*, a Greek word meaning *all, whole, and entire, total*) is the idea that all the properties of a given system (physical, biological, chemical, social, economic, mental, linguistic, etc.) cannot be determined or explained by its component parts alone. Instead, the system as a whole determines in an important way how the parts behave. The idea has ancient roots. [37]

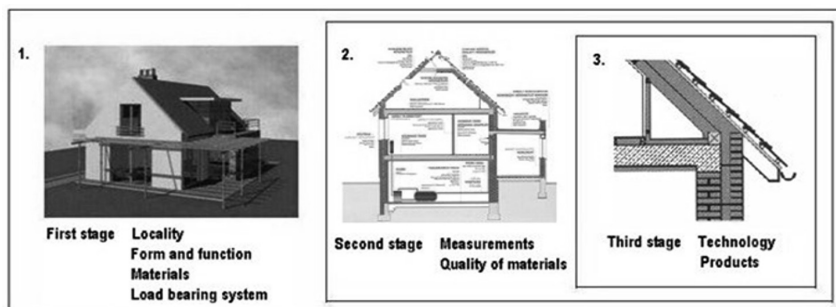


Figure 12 [8, 9, 10] Stages of holistically approached architectural design process

Analysis of impacts, requirements, and structural performances of each design stage can be the common ground of the dialogue between the architect and the experts according to the Performance Based Design method (PeBBu - CIB) [11]. (Fig. 13.) In Performance-Based Building Design evaluation of each design factors and aspects focuses on demands and on required performance in use.

Performance requirements translate user requirements in more precise quantitative measurable and technical terms, usually for a specific purpose. Steps of evaluation process are given below. Order of the performance based structural evaluation steps cannot be changed and need to be worked out for each condition (effect) due to the interaction of the parameters. We have to take into consideration the whole complexity of aspects and available data during the design process

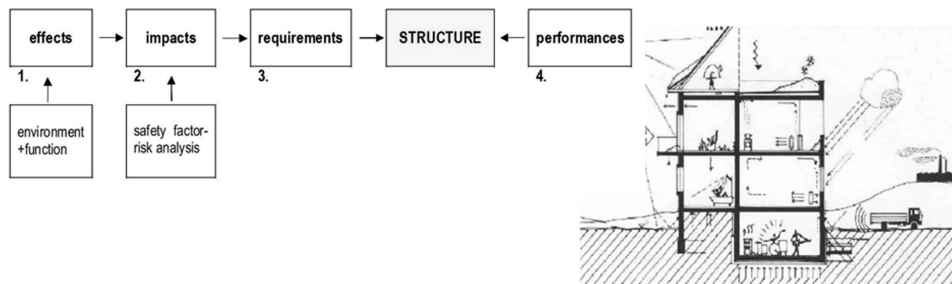


Figure 13 [12] Performance based evaluation method of architectural decisions

Efficiency of design process depends on the adequacy of the data applied. Architectural decisions can be correct if they are based on a comprehensive, real, and up to date and appropriate Database. [13] Database is always unique and local. The essential part of the decision process is a properly modifiable Project-oriented Site-specific Database, continuously fitted to the project, consisting of real, up to date and comparable data. (Fig. 14.) In this Database system, the compilation of information - according to the project and site - starts at the beginning of the design process, with the collection of the basic data of social, cultural, functional, natural, structural, material, economical, technological information. This multilevel database should be fitted to the project from the preliminary plan until construction phase. The applied systemized parameters should be controlled and consciously selected.

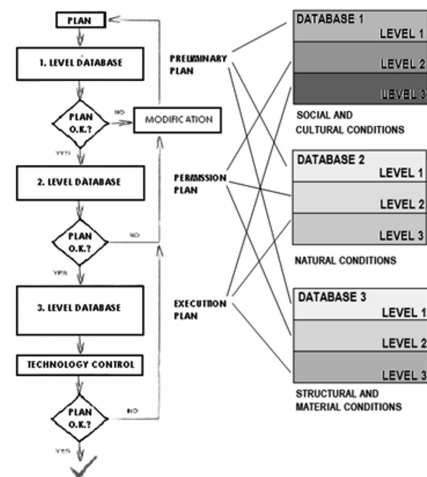


Figure 14 [14, 15] Project oriented complex database

The Holistic Performance Based design method responding on the surrounding conditions integrates skills, knowledge and tools of “passive” and “smart” design elements into a more conscious complex design process. In this design process the computer aided technologies are tools for architect, but not independent creative “intelligences” far from the human attitudes and real natural circumstances.

Holistic Performance Based (HPB) design process provides awareness whole complexity of technical knowledge for architects. By this way, the architectural and structural decisions made through the evaluation of real parameters and the complexity of the measurement will be more secure. As the attached figure shows the freedom of choice is the highest in the beginning, because later the decisions had been done earlier limit modifying of particular elements. As the project takes shape and becomes more detailed the degrees of freedom and the possibilities of choosing better alternatives are reduced. This complex attitude should be an integrated part of the designing process from the very first step. (Fig. 15.)

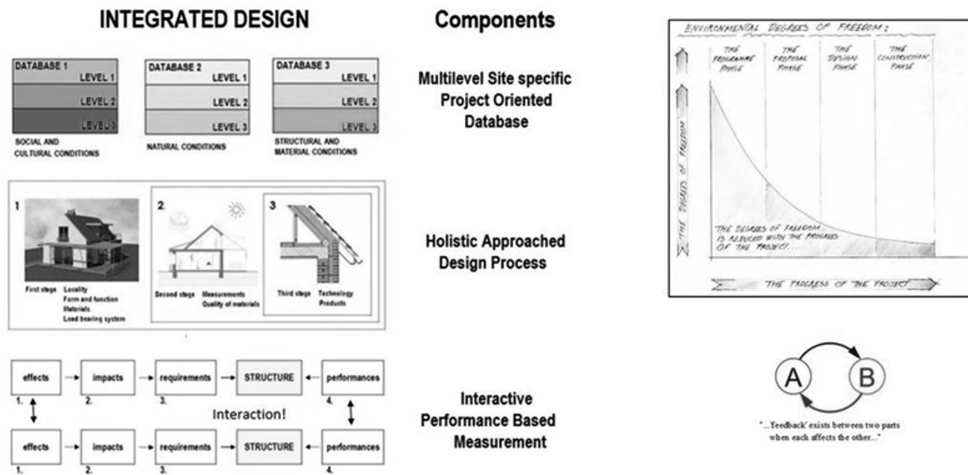


Figure 15 [16] Components of complex integrated holistic performance based architectural design

Matching of preliminary environmental parameters and required building parameters by holistic performance based evaluation method according to the multilevel project oriented site specific database is the basis of this complex design process. (Fig. 16.)

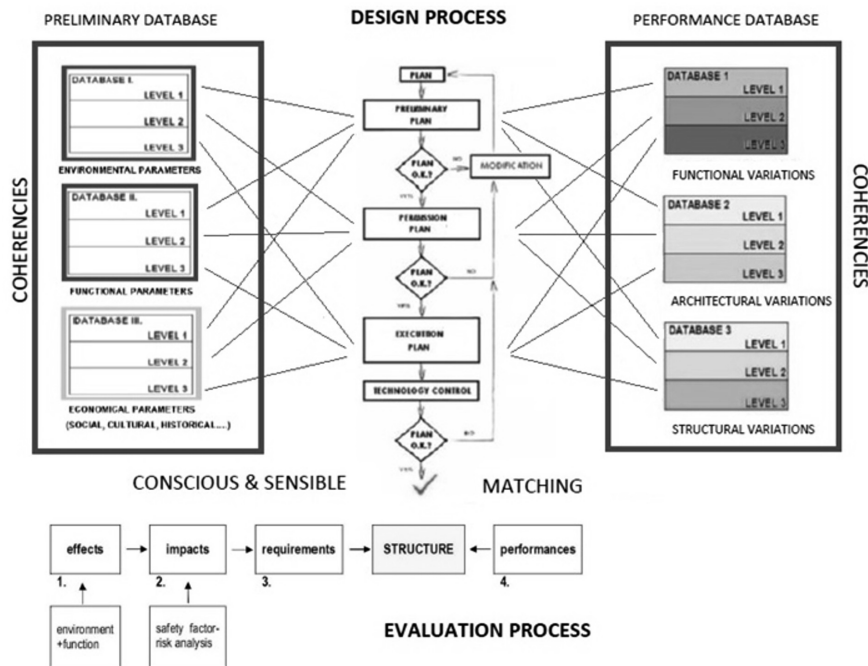


Figure 16. Summary of complex holistic performance based architectural design process based on the continuously fitted database system

This method could be used not only in design practice, but in university curriculum as well. [17, 18, 19] Tutorial practice should help students to discover how architects can capture locality, and how they can build databases to be used from the very first step of the design process. This teaching method should be always a multidisciplinary effort joining not only the various branches of architecture, but also involving IT specialists, meteorologists, civil engineers, economists, etc. We have to provide integration of several design aspects, requirements and tools into creative design process based on well systemized and determined site specific comparative database to achieve an optimum architectural and structural solution fitted to the given circumstances and demands.

ERASMUS program at Budapest University of Technology and Economics helps not only Hungarian but foreign students as well to use the complex holistic design method in their design tasks. In the comprehensive design studios the teachers of several professional fields help student to develop

step by step their own optimum version for the given design program. Students match the environmental (natural, social, functional, economic) parameters to the possible architectural, functional, and structural solutions. (Fig. 17.) This conscious design process allows them to define and compare design choices in connection with performances of building and surroundings, to recognize, that each requirement criteria has different priority in several design situations.

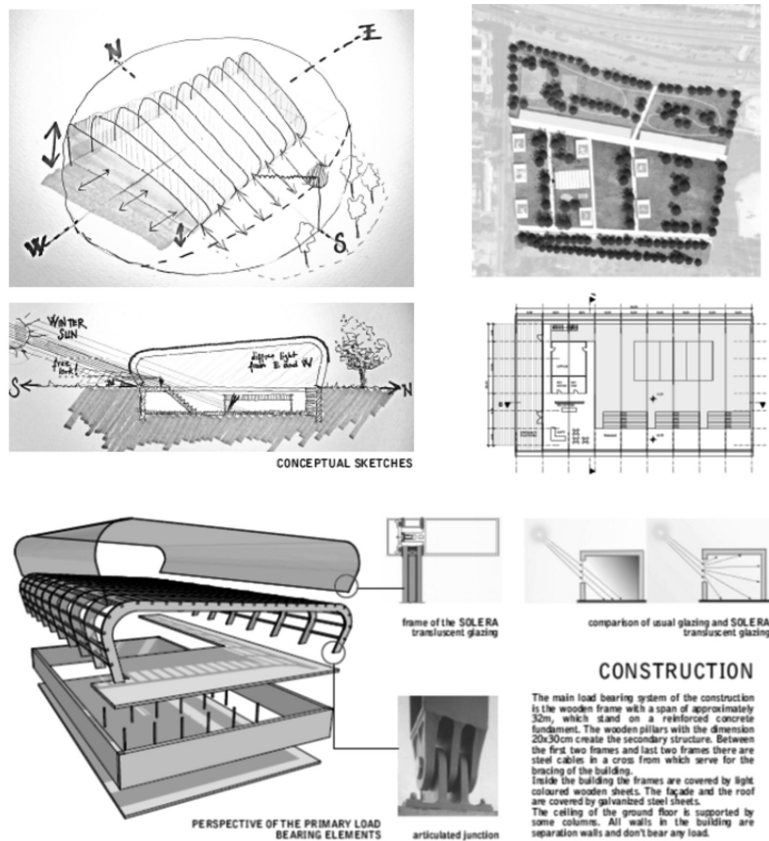


Figure 17 Student's semester project according to on complex integrated holistic performance based teaching method [19]

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To Follow Or Not To Follow Design Standards: A Question For Sustainable Coastal Engineering

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Abstract

This paper is concerned with what a contractor should do to fulfil his design obligations under a construction contract to assist the fulfilment of a sustainable design and/or end product. It considers this in relation to a recent Court of Appeal case law concerning coastal engineering, as this is an area where sustainability is at the forefront. This area concerns the use of relatively recent technology. It is not always clear from the provisions in construction contracts servicing recent technologies, how contractors can be protected from legal liability, even when the designer has apparently done all that is required under the contract. This is illustrated by the recent case law *MT Højgaard A/S v E.ON Climate and Renewables UK Robin Rigg East Ltd* and another [2015]. This paper will examine, the guidance in this Court of Appeal's judgement regarding a contractor's liability for design involving a fitness for purpose obligation, and the extent to which this may be tempered by other terms in the contract. This paper will combine such guidance with an explanation of the legal approach to the analysis and construal of contracts. In doing so, this paper will attempt to address questions which often arise concerning a contractor's design liabilities, such as, should a party to a contract follow the letter of the contract or should they follow standards set by professional organisations when carrying out their design task, and what should the parties do if there is a conflict between the terms of the contract and design standards?

Overall, it will evaluate how any conflicts may be removed with reference to current law and professional practice. The recommendations are applicable to all with design obligations. In summary they are that the proposed contract should be analysed by both parties to consider the various interpretations of provisions. To avoid disputes, a common interpretation needs to be agreed on in advance of entering into the contract. The conditions of a contract need to be clearly identifiable within the contract, unambiguously stated and a hierarchy and interpretation agreed upon by all parties to the contract in advance of the contract's application to the project.

Keywords: fitness for purpose, contract, design life, engineering

1. Introduction

Sustainability in construction is concerned with design, construction and operation, but also with contracts to enable such events and to avoid chaos. As Hibberd (2015) said, until ‘consideration of matters related to sustainability’ are ‘an intrinsic and an inherent component of one’s thinking – not a separate consideration’, contracts and especially the accompanying guidance on contracts’ will continue to play a very important role. He makes the seemingly obvious point that the contract should reflect the decisions which should have been made, however, in practice, this is not often straightforward. The process of agreeing an appropriate and effective contract is complicated by new technologies and innovations. The performance/sustainability of the structure and/or components may be uncertain. The performance, for example, of wind turbine foundations is subject to variables, which cannot always be predicted. As Scottish Development International (2010) reports:” Stable sea conditions are required for foundation installation and increased downtime is therefore to be expected with projects further offshore and in deeper waters.” (p.27). This paper considers a recent judgment of Court of Appeal which concerns the design life of the foundations of wind turbines and the design liability of its contractors. It is particularly important for designers involved in coastal engineering construction projects understand their legal responsibilities and check that their contracts protect them from liability where possible. This may avoid delays, assist an efficient realisation of a smart sustainable construction, and avoid costly arbitration or litigation. It is also important to consider this because, as reported by O’Keeffe and Haggett (2012), offshore wind is likely to make the single biggest contribution towards UK government renewable energy targets across the UK because the UK has over 33% of Europe’s potential offshore wind resource, with the majority of that resource lying off the coast of Scotland (p 3711).

Coastal engineering and construction contracts, including those used in the offshore oil and gas and wind farm sectors, often involve the use of design and build type contracts where the contractor is given responsibility for both the design and the construction itself. In such cases, it is increasingly common for employers to insist on absolute warranties. Many of the popular standard forms, such as the LOGIC standard contracts, include absolute fitness for purpose obligations. Contractors who accept these provisions should be aware that there is a high risk of potential liability. The contractual obligation that the work will be fit for purpose is quite different from the reasonable skill and care obligation that is more usually undertaken by designers of constructed facilities. It involves a strict liability regardless of fault. However, the all-important question in every case is "fit for what purpose?" Another question that arises with design contracts is what is meant by standard phrase design life, in the context of the contract? As Michael Curtis QC (2014) stated in his recent article, “There is no single definition that applies in all contexts.” (p1) With large projects and with coastal engineering projects the meaning of key phrases in the context of the purpose that the contractor has to achieve may be unclear. This is because it often has to be deduced from a collection of contractual documents of different authorship, containing ambiguous wording.

It is therefore not always clear from the contract, how contractors with design and build contracts can be protected from liability, even when the designer has apparently done what is required under the contract by strictly complying with the international recognised design standards referred to in the contract. This is illustrated by the recent case law *MT Højgaard A/S v E.ON Climate and Renewables UK Robin Rigg East Ltd and another* [2015]. The Court of Appeal judgment has helped to clarify how a designer can work out what he should do to avoid liability when things go wrong. But this is not enough. A contractor also needs to understand how contracts are construed and interpreted by lawyers, particularly by judges, as well as how key provisions are interpreted. This paper will therefore consider, with reference to case law, how designers may ascertain their legal obligations when there are conflicts between the terms of the contract concerning the designer's obligations and the design standards. It will assess current legal practice and provide guidance to contractors to assist them with working out the extent of their legal obligations under contracts regarding design.

This also requires consideration as to how contracts are interpreted by the Courts, whether there is a hierarchy of terms in a contract, and where there is a conflict, that is, inconsistency or ambiguity, between terms, how to assess which term has precedence in determining the designer's professional obligations.

2. Key Case Law

2.1 Facts: *MT Højgaard A/S v E.On Climate And Renewables UK Robin Rigg East Ltd & Anor* [2015]

Firstly, this paper will consider guidance given by the Court of Appeal in the currently leading case in this matter, *MT Højgaard A/S v E.On Climate And Renewables UK Robin Rigg East Ltd & Anor* [2015] EWCA Civ 407 (30 April 2015) (MTH). The Court of Appeal is the second highest court in the United Kingdom just above the High Court. In this case, the Court of Appeal was asked to reconsider the decision of the lower court, the Technology and Construction Court (TCC), which is part of the Queen's Bench Division of the High Court.

In 2006, E.On Climate and Renewables UK Robin Rigg East Ltd and E.On Climate and Renewables UK Robin Rigg West Ltd ("E.ON") entered a contract for €100 million with MT Højgaard A/S (MTH) to design, fabricate and install the foundations for 60 wind turbine generators at the Robin Rigg offshore wind farm in Solway Firth. This firth forms part of the border between England and Scotland, between Cumbria (including the Solway Plain) and Dumfries and Galloway. It stretches from St Bees Head, just south of Whitehaven in Cumbria, to the Mull of Galloway, on the western end of Dumfries and Galloway.

The Contract required MTH to carry out the Works with due care and diligence, and to ensure that they were fit for purpose. MTH's designer, Rambøll had relied on the international standard DNV-OS-J101 (J101) when carrying out the design of the foundations and the grouted connections. The reason he did this is because the fitness for purpose requirement in the contract was determined in accordance with the Specification, that is, the Technical Requirements, using

Good Industry Practice. The latter is generally defined to mean performance with the skill and prudence to be expected of an appropriately skilled and experienced contractor, in a manner consistent with recognised international standards. An objective test is applied. This is explained and elaborated upon in joint publication with Scottish Renewables (2015) at p. 4. The Technical Requirements specified that MTH must comply with the internationally recognised standard DNV-OS-J101 (“J101”). It also included a requirement that the foundations would have a service life of 20 years. So MTH complied with the contract by following J101. However, J101 contained a fundamental calculation error. MTH’s designer, Rambøll was unaware of this when it carried out the design, (as were designers in general at this time). (But the fact that no-one knew the standard was faulty did not assist MTH at the TCC hearing.)

In 2009 it was discovered that movement was taking place in the grouted connections at a Dutch offshore wind farm which had a similar design to that at Robin Rigg. Shortly after completion of the works, the grouted connections in the foundations started to fail. The error in the J101 standard had resulted in a significant overestimation of the axial load capacity for wind turbines with grouted connections. In April 2010 it was found that the wind turbines at Robin Rigg were suffering from the same defects. A scheme of remedial works was developed and the remedial works were commenced in 2014. The parties agreed the cost of the remedial works which amounted to €26.25 million.

2.2. MTH: Technology & Construction Court (High Court)

E.ON then took MTH to the Technology & Construction Court for breach of contract, claiming damages for the cost of the remedial works. Mr Justice Edwards-Stuart found that MTH had indeed exercised reasonable skill and care and that it had complied with the DNV-OS-J101 standard. Neither party had been negligent. The problem, the judge said, was that the Contract and Technical Requirements stated that “The design of the foundations shall ensure a lifetime of 20 years in every respect...” The judge said that meant the contractor had warranted that the foundation structures which it designed and installed for an offshore wind farm would have a service life of 20 years. But they clearly did not fulfil this promise, as the foundations had failed shortly after completion.

The Court’s reasoning relied on its examination of certain paragraph in the contract, viz., 3.2.2.2 (2) of the Technical Requirements, which stated that "The design of the foundations shall ensure a lifetime of 20 years in every aspect without planned replacement": and paragraph 3b.5.1 of the TRs which also stated that "The design of the structures...shall ensure a lifetime of 20 years in every aspect without planned replacement"; and clause 8.1 (x) of the Contract which required the contractor to complete the works such that the "Plant and the Works as a whole shall be free from defective workmanship and materials and fit for its purpose as determined in accordance with the Specification using Good Industry Practice." Note the mandatory language used, viz., ‘shall’ in each clause. This term is normally associated with absolute warranties. The TCC found that these clauses required MTH to provide foundations with a service life of 20 years; and that the failure of the foundations was therefore a breach of contract, including a breach of clause 8.1 (x)

Therefore, by accepting overall design responsibility for the Works, the contractor, MTH, although it did not do anything wrong, was held responsible for the risk of there being an error in the standard J101. The international standard did contain an error, which materialised, and therefore the High Court held MTH liable for the consequent damage.

2.3 Fair or Unfair?

You may consider this an unfair decision, as the contractor had been a good designer in following the approved design standard required by the contract. It does not seem right that it should be held responsible for the intrinsic error contained in the standard, which no-one knew about at the time of the damage. But in law, a warranty can be like a guarantee or entail strict liability. So it does not matter if you have done nothing wrong. You may still be liable because you agreed with your client that you would do things or provide certain things of a certain standard, which do not happen or turn out not to be of that standard, even though it is completely not your fault. If, for example, you tell your roofer that he should supply tiles which should have a ten year life and the roofer agrees to provide the tiles, but they do not last a year, because they were manufactured badly, then the poor roof tiler is responsible to replace the tiles at his own expense, even though, despite a reasonable inspection of the tiles he could not have known that they were faulty. Here the judge is saying that the contractor had warranted that the design itself, not the product that results from the design, would have a life of 20 years. Note the use of the mandatory words ‘shall’ in each of the paragraph referred to by the Court. This will usually indicate an absolute obligation, whether or not there is fault.

2.4 MTH: Appeal to the Court of Appeal

Luckily for MTH, the contractor, the Court of Appeal disagreed with the reasoning and decision of Mr Edward Stuart in the Technology and Construction Court. One would have thought the judiciary in the Technology and Construction Court were the experts in such matters, as this is a specialist court, however, when it came to the law and the interpretation of the contract the higher Court, the Court of Appeal knew better. It reversed its decision. Consequently, E.ON bears the agreed costs of the remedial works amounting to €26.25 million. They may yet seek leave to appeal to the Supreme Court. So how did this come about?

MTH had appealed to the Court of Appeal on the basis that the TCC’s interpretation of the Contract was wrong. E.ON then cross-appealed on the ground that MTH had committed other breaches in failing to carry out further testing prior to carrying out the Works, which would have discovered that there was an error in the J101 standard. Regarding the cross-appeal, the Court of Appeal did decide that MT Højgaard was in breach of the test data and experimental verification requirements, but it concluded that those tests would not have revealed the defects that had occurred, and therefore the breach did not cause any loss. Therefore, E.ON was only entitled to recover nominal damages of £10 for its cross-appeal.

The Court of Appeal explained its view that the TCC’s interpretation of the Contract was wrong. It argued that the wording in Clause 8.1(x) that the works as a whole should be “fit for

its purpose” was qualified by the phrase “as determined in accordance with the Specification using Good Industry Practice”. It accepted that the Contract defined “Good Industry Practice” as requiring the exercise of reasonable skill and care as well as compliance with the DNV-OS-J101 standard. It concluded that MTH had exercised reasonable care and skill, and that they had followed the design standard.

The Court of Appeal particularly considered the wording in the Technical Requirements which said that “The design of the foundations shall ensure a lifetime of 20 years”. The Court agreed that it was clear from the contract that MTH was required to assume full responsibility for the design as well as for the installation of the structures comprising the Works. However, crucially, the Court of Appeal made a very clear distinction between “design life” and “service life” saying that if a structure had a design life of 20 years, that did not mean that it would function for 20 years, that is, it didn’t mean that it would have a service life of 20 years. What the Court said contradicted the TCC’s decision that the contractor had warranted that the foundation structures which it designed and installed for an offshore wind farm would have a service life of 20 years. In other words, The Court of Appeal concluded that MTH did not guarantee or warrant that the foundations would have a ‘service’ life of 20 years.

This approach seems to be taking a literal interpretation of the words by limiting the guarantee to the design of the foundations. But surely this is not a common sense interpretation. Why would the client have agreed to that, when what is of vital importance to him is that the foundations will last for 20 years, e.g., “The design of the foundations shall ensure that the foundations have a service life a lifetime of 20 years [my inserts]”. If the design is properly carried out, then the foundations’ service life should be 20 years, just as in the case where you have agreed with your supplier that tiles he supplies must have a life of 13 years. This does not mean that there cannot be maintenance of the structure over time. There is no reason why this would detract from the obligation. The service life would end when it is not possible to replace one or more of the components essential for its operation.

The problem seems to be, as Curtis (2014) stated, that ‘it is essential for a contract or specification to define precisely what the term design life is supposed to mean in the context in which it appears. Otherwise it is likely that the parties’ expectations about its meaning will be very different . . .’(p 4). For example, does it mean that the foundations will function for 20 years without any maintenance or does it mean that the foundations will last for 20 years provided it is properly maintained? In reaching its decision the Court must also consider the other provisions of the contract as well as the construction of the contract as a whole, and so to shed light on the Court’s reasoning for this decision, this paper will consider how the court goes about doing this.

3. Contract Interpretation

3.1 The intentions of the Parties

Firstly, it should be noted that the parties' negotiations prior to a contract being agreed are irrelevant, when determining the interpretation of contract provisions. In *Chartbrook Ltd -v- Persimmon Homes Ltd* [2009] UKHL 38, the House of Lords confirmed that that evidence of pre-contractual discussions should not be used as a tool of construction. However, relevant background fact or statement known to both parties may be relevant where a party claims that the written contract should be corrected to reflect the terms that were 'actually' agreed by both parties. The Court or Tribunal also does not take the subjective intentions of the parties into account when interpreting the contract. It is not interested in what they 'say' they intended to agree. Rather, the law uses an objective approach to interpretation. It will first give the words of the provision their natural meaning, so that the words that were actually used in the contract are be construed in the way that they would be understood by a (hypothetical) reasonable person, with the background knowledge available to both parties at the time the contract was made. The approach is not concerned with the way each party may argue they were used: *Chartbrook Ltd -v-Persimmon Homes Ltd* [2009] UKHL 38. It will then consider how the provision fits into the contract as a whole, i.e., what do the words really mean in the context that they were used?

So the trend in recent case law is that the actual language used in the contract is given priority, unless the language is ambiguous or unclear. This approach is apparent in the judgment of the Court of Appeal. It provides a useful summary of the principles of contract interpretation. In a key passage, at para 87, the Court's judgement delivered by Lord Justice Jackson states that, "a court seeking to construe the contract between E.ON and MTH must postulate a reasonable person (X) having all the knowledge available to those two parties. The court must consider what X would have understood clause 8.1 of the conditions and TR paragraph 3.2.2.2 (2) to mean. This is an iterative process, which involves checking each of the rival meanings against the other contractual provisions and investigating its commercial consequences".

The Court of Appeal did agree with arguments that the fitness for purpose requirement was determined in accordance with the Specification (the Technical Requirements) using Good Industry Practice, which, in summary, meant performance with the skill and prudence to be expected of an appropriately skilled and experienced contractor, in a manner consistent with recognised international standards. The problem, the Court argued, is that the Technical Requirements are inconsistent with the Contract conditions which required "due care, professional skill, adherence to good industry practice, and compliance with the Employer's Requirements. But the Court found this resolvable since the contract had provided a hierarchy of terms.

3.2 The Hierarchy of Terms in a Contract

It is usual with complex commercial contracts for a number of people to be involved in negotiating the different parts of the contract. This can make it challenging to know which

terms, which are given in provisions of the contract, should be given priority over others, if there is any conflict in the language or interpretation. The contract will consist of a number of contractual documents, prepared by different people. These will include for example, the main terms and conditions, as well as/or technical requirements, specific schedules or appendices that deal with certain issues such as 'defined' terms, payment arrangements, service levels and the delivery timetable especially on larger projects. But it is not always clear which are the most important terms to be followed where there is conflict between them. So the parties often insert a 'hierarchy' or 'order of preference' clause (also referred to as a provision) into their contracts to safeguard against potential discrepancies between an agreement's various provisions and parts of the contract. Such clauses typically provide that, in the event of a conflict or inconsistency between the language and terminology used in contractual provisions (in this case “design life”, “service life” and even “lifetime”), or parts, certain clauses or parts will prevail over others to resolve the conflict. However, the Courts do not jump straight to this hierarchy clause. They first attempt to reconcile any contradictory or overlapping clauses.

Recent Court cases demonstrate that the Courts are reluctant find that the contract documents are inconsistent with each other. They would rather attempt to give effect to an interpretation which avoids this, or reconciles any conflict: *RWE Npower Renewables Ltd v J N Bentley Ltd* [2014] EWCA Civ 150. The Court’s judgment in *MTH Højgaard A/S* explains that in the contract in question, where there is inconsistency between terms of a contract, the terms which are the ‘contract conditions’ must be followed, because the hierarchy of terms clause says that the contract conditions are above the Technical Requirements in the contractual hierarchy of terms. The Court seemed to be implying that the TCC did not seem to have considered the order of hierarchy of the provisions of the contract when considering the contract as a whole.

The Court of Appeal found that clause 5.3 of the contract provided that the contract conditions which required “due care, professional skill, adherence to good industry practice, and compliance with the Employer’s Requirements, take precedence over other contractual documents, and the Employer’s Requirements came fourth in the order of precedence. The judgement noted at par 102 that the phrase “Good Industry Practice” is defined in the List of Definitions (a document which has parity with the conditions of contract in the order of precedence) and that although obligation requires the exercise of reasonable skill and care, as well as compliance with J101, it did not require or impose any form of warranty as to the length of operational life. Since the contractors had complied with these contract conditions they had fulfilled their obligations, despite the fact that the international standard was flawed.

The Court of Appeal argued that the overall drafting of the Technical Requirements was inconsistent with an intent to impose an absolute guarantee of a 20 year operational lifespan, since the ‘detailed’ ‘input’ requirements of the Technical Requirements (which required, among other things, compliance with J101) were inconsistent with an ‘output guarantee’ of a 20 year lifespan.

The Court concluded that one could not conclude that MTH gave a warranty requiring a 20 year service life (as opposed to design life) based on the individual provisions of the Technical

Requirements (para 106). The Court finally added that a reasonable person in the position of E.On and MTH would know that the normal standard required in the construction of offshore wind farms was compliance with the international standard, but that such compliance was not absolutely guaranteed, to produce a ‘service’ life of 20 years (para 104).

4. Discussion

So after deciding that the hierarchy of terms clause resolved this matter, the Court seems to cover its tracks by also justifying their decision by referring to the objective approach, the views of the reasonable man in the position of the parties. Firstly, regarding the hierarchy of terms clause, it has been recently held in *RWE Npower Renewables Ltd v J N Bentley Ltd* [2014] EWCA Civ 150, that it is only where there is a clear and irreconcilable discrepancy that the hierarchy clause should be resorted to. Effectively, it is a clause of last resort, not first resort. A clear and irreconcilable discrepancy does not seem to have been identified. It may be argued that the Court has not reverted to the hierarchy clause as a last resort, and its decision may be open to appeal on this point

Designers clearly must do what is required under the contract according to the standard required under the contract, to which they have supposedly agreed. Whether or not the designers will be successfully sued for damages for breach of contract for the consequences of errors in the design standard they could not have been aware of, will depend on the standard of care required by the contract. However, where a design standard is required to be followed, and the quality or duration of the standard of care required is uncertain due to conflicting wording in various provisions, or because of the effect of other provisions in the contract, it may be difficult to ascertain what were the intention of the parties at the time they made the contract.

It is unusual for a professional designer to agree to a guarantee his design will be fit for purpose or that the design life will be fit for purpose. However, a contractor, in a design and build contract is responsible for the design as well as building it, and is required to produce a structure fit for purpose- whether it is a bridge or wind turbine generators. This goes to the root of the contract. Unless the structure can do the job it is of no value. However the Court of Appeal seem to have got around this difficulty by arguing that there is a difference between the design life and the service life of the structure. But this seems to contradict current knowledge. It is standardly accepted that wind turbines are typically designed for a 20 year design and service life. For example, *Windmeasurementinternational* states that ‘Every machine has a set design lifetime based on how long the parts are expected to last. . . . The components of a wind turbine are typically designed to remain operational for twenty years.’ So both the design life and the service life should be at least 20 years. This reality contradicts the view of the Court of Appeal which focuses much more on the construction of the provisions in the contract, rather than on a prior investigation of the commercial reality, The latter, as the above explains, indicates that it is likely that a reasonable man in the position of the parties would have intended to agree to guarantee a design and service life of 20 years. The Court of Appeal in *MTH* does not clearly seem to have considered this.

The Court did refer to some helpful guidance about the construction of contracts, even if it did not take it too seriously. Lord Jackson in the Court of Appeal cited the judgment of Lord Clarke in *Rainy Sky SA v Kookmin Bank* [2011] UKSC 50; [2011] 1 WLR 2900 who observed that “...if there are two possible interpretations of a provision, the court is entitled to prefer the construction which is consistent with business common sense”. What makes more sense than for the contractor to be liable for a 20 design and service life of a turbine when this is standardly accepted by the industry as normal?

Lord Jackson also cited the judgment of Lord Collins SCJ in the case of *Re Sigma Corp* (in administrative receivership) [2009] UKSC 2; [2010] 1 All ER 571 in which it had been held that an “...over-literal interpretation of one provision without regard to the whole may distort or frustrate the commercial purpose”. In this paper’s view, both the views of Lord Clarke and Lord Collins could have been considered more seriously, with more attention given to the commercial realities, when attempting to ascertain the intentions of the parties at the time they entered the contract. This step should have determined the outcome of the case.

4.1 Recommendations

With complex projects or those involving new technology, it is worth paying for the extra time and fuss involved in having an experienced lawyer to ensure that contracts are clearly drafted to reflect the precise agreement between the parties, as accurately as possible. This will avoid incurring far more costs further down the line.

The proposed contract should also be analysed in the context of addressing the following questions. Are any of the provisions relating to design responsibilities open to misinterpretation or ambiguity? Could a provision be read in different ways? What do the clauses mean in the wider context of the contract as a whole? Could the provision be misunderstood? Consider how the provision could be applied to what may go wrong. Is this the application you intended?

Where there are conflicts between the provisions of the contract, and a hierarchy of terms clause/provision is not given in the contract, then the conditions of the contract will somehow need to be identified. They go to the heart of the contract, and so what they say impliedly takes priority over other provisions. But identifying which provisions are conditions should not be left up to the Courts. They may not get it right, with resulting further appeals, costs and delays to projects. To avoid such disasters, it should always be clearly stated in the contract what are the conditions of the contract, i.e., ‘It is a condition of the contract that ...’ and if some of the provisions have similar or conflicting wording, then it needs to be clearly, unambiguously stated in the contract which ones have priority, should a conflict arise. All parties to a contract should be made be given clear notice of the conditions and priorities of provisions in the contract before agreeing to it or signing it. Such notice should be in writing through legal representatives to avoid disputes along the lines that these are unusual provisions which were not drawn to attention. If there is any likely conflict regarding the interpretation of the words or phrases in a contract, this must also be sorted out before the contract is agreed. One interpretation of them should be agreed by the parties.

It is therefore recommended overall, that where a clause is of vital importance to the employer or contractor, that party needs to obtain agreement with the other party to the effect that it does have such importance, and then, this must be highlighted in the contract. This means that the wording in the clause should be very clearly stated and the clause marked in a prominent position as the main condition of the contract having priority over all other conditions of the contract. For example, if E.ON had really wanted an absolute binding 20 year service life warranty, to avoid later argument, it should have insisted on that provision featuring prominently and unambiguously within the conditions of contract, rather than being closeted away in the Technical Requirements.

5. Conclusions

The MT Højgaard A/S case demonstrates the problems that can arise with complex contracts when various documents from different sources are incorporated at different levels into a contract. Contractors/designers need to assess their potential liability regarding inconsistencies between them, and attempt to remove any inconsistencies before agreeing to the contract.

The Court of Appeal supported the previous comments of the High Court that if the contract wording is sufficiently clear, an express obligation to construct a work capable of providing a 20 year service life can override the obligation to comply with the plans and specifications, which includes complying with the design standard. Then the contractor would be liable for the failure of the work, notwithstanding that it had been carried out in accordance with the plans and specifications.

It must be clear from this paper that fitness for purposes obligations for contractors who are designers or designer-builders should be avoided, excluded or limited, if possible. This is because if the product fails, a party may be liable for all the damage incurred, even if they exercised reasonable skill and care, and even if they followed the stipulated design standards to the letter.

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Energy generation and matching in a net zero-energy building in Finland

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Abstract

All new buildings in the EU are to be nearly zero-energy buildings (nZEB) by the end of 2020. Energy efficiency, reduced demand, and onsite renewable energy systems, are key characteristics of nZEBs; when these features are combined, the generation from the supply systems may exceed the energy demand of the building. Such has been the case in the zero energy building named Villa ISOVER®. It integrates photovoltaic panels, solar collectors, a ground-source heat pump and grid interactions, and adheres to strict regulations by the National Building Code of Finland. As well, a monitoring system records data from several channels such as energy generation and demand measurements, which allows to analyse the generation, demand, import and export of energy. In this paper, the data is first used to calculate the zero-energy balance of the building. Next, two indices: the onsite electrical energy fraction (OEFe) and the onsite electrical energy matching (OEMe) are calculated. The OEFe indicates the proportion of the total electrical demand which is covered by the onsite generation, and the OEMe indicates the proportion of the total electrical generation which is consumed in the building and system rather than being exported or dumped. The seasonal and time-resolution dependencies of these indices as well as different calculation methods have been studied. A series of outcomes have been deduced based on the measurement data. The annual net energy consumption of this building in 2014 is 15 kWh/m²a, which is thus, strictly speaking, a nearly zero-energy building. Furthermore, both the PV generation and electrical load are seasonal dependent, though in reversed behaviour: while generation is high during summer and low during winter, the load is low during summer and high during winter. This contrast leads to poor annual OEFe and OEMe, at 16% and 22%, respectively. Said indicators are indeed sensitive to

time-resolution, depending on the available measurements and calculation method: coarser time resolutions may lead to overestimations of the matching capability. Finally, the recorded exchange with the electrical grid is seasonal-dependent: the normalized net-exported energy can be as high as 60% during summer, and as low as -40% during winter.

Keywords: Zero energy buildings, real measurement, matching analysis, grid interactions, onsite photovoltaic.

1. Introduction

All new buildings in the EU are to be nearly zero-energy buildings (nZEB) by the end of 2020. Energy efficiency, reduced demand, and onsite renewable energy systems, are key characteristics of nZEBs; when these features are combined, the generation from the supply systems may exceed the energy demand of the building. While this may at first appear to be a beneficial situation, it may represent an unfavourable condition for the distribution grid, and even for the user. For the grid, handling the surplus energy can be a challenge during peak hours. This is particularly risky when photovoltaic panels are present, as solar power is usually available around noon, when the grid utilization is high. For the user, exporting energy may not be the most attractive option. Self-consumption tends to be the preferred way to use of onsite generated energy, as the savings from avoiding electricity purchases are usually larger than the income from selling excess electricity to the grid. Thus, attention should be paid to the match between energy generation and demand, so as to identify the proportion of the generation which may be consumed onsite, and to predict how high the surplus fed to the grid could be. The purpose of this study is to analyse the generation, demand and interaction with the grid of a nZEB in southern Finland, and to study the behaviour of match indicators based on different methods and time-resolutions.

2. Zero-Energy Building Villa ISOVER[®]

Villa ISOVER[®] is a building conceived by ISOVER[®] and Fortum[®] to test the performance of a zero-energy building and its interaction with the electrical grid. It is a single-family house with a 175 m² net floor area built for the Housing Fair 2013, which was the winner of a design competition. The building is located in Hyvinkää, southern Finland. It integrates PV panels, Solar-thermal Collector (SC), a ground-source heat pump (GSHP) and an air handling unit (AHU); there is no connection to an external heating network, as the GSHP and SC fulfil the heat demand. A key feature allowing this configuration is the highly efficient thermal insulation. Thus, the building follows the design principle of first minimizing consumption and then using the locally available energy resources to fulfil the remaining needs as far as practical. A monitoring system keeps track of several heat and electricity onsite measurements, such as PV generation, electricity import and export to the grid, heat generation by SC and GSHP, and domestic hot water (DHW) demand, among others. As well, solar radiation and inside and outside temperatures are monitored. The data has a time-resolution of 1 hour. The building is presented in Figure 1.

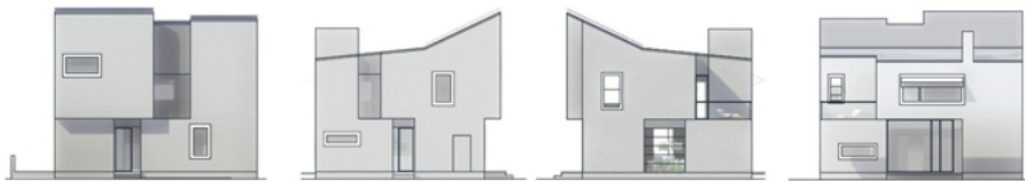


Figure 1: Villa ISOVER[®] depicted from four directions [ISOVER[®], 2013]

3. Energy Monitoring and Matching Analyses

3.1 Energy Monitoring Analysis

The original recorded data is based on a recording resolution of 1 hour over the year of 2014. The PV generation after the inverter is depicted in Figure 2, where a significant seasonal dependence can be seen. During the summer time, peaks of a magnitude of 6-7 kW can be noticed, whereas during the winter time, the magnitude of the PV generation after the inverter is mostly lower than 1 kW. The recording system also records the grid interactions between the building and the electrical grid. The electrical power imported from the electrical grid to the house and the electrical power exported from the house to the electrical grid are both recorded.

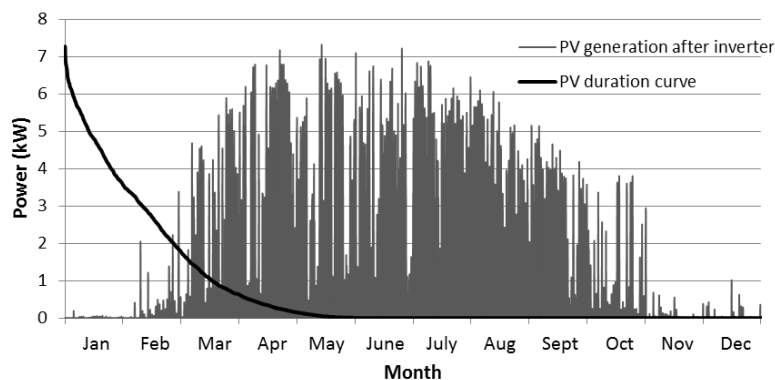


Figure 2: The recorded hourly PV generation after inverter

Figure 3 and Figure 4 depict the recorded hourly power imported from and exported to the electrical grid. As shown in Figure 3, the electrical power imported from the electrical grid also shows a seasonal-dependent characteristic. During the months of October to April, i.e. the winter time, the magnitude of the hourly electrical power imported from the electrical grid is between 0 kW and 5 kW. During the months of May to September, i.e. the summer time, the magnitude of the hourly electrical power imported from the electrical grid is within a range of 0-3.5 kW. The generally higher magnitude for the imported electrical energy in the winter time is mainly due to the higher heating load during the winter season, which can cause a more frequent operation of the GSHP and the AHU heating unit, as well as pumps and auxiliary equipment. On the other hand, during the summer season, the space heating load and the AHU heating load are quite low, and the DHW heating load can be mainly covered by the SC heating power, leading to a much less frequent operation of the GSHP and a lower total electrical consumption. Moreover, as shown in Figure 4, during the summer season the solar resource is sufficient, which means that the PV generation helps to cover the onsite energy load, which leads to less imported energy.

As can be seen in Figure 4, the hourly exported power to the electrical grid also shows a significant seasonal-dependent characteristic, with a much higher magnitude during summer than during winter. During the summer season, the exported power from the building to the electrical grid can reach a magnitude around 7 kW, whereas during the winter season, the

exported power is mostly around zero. The main reason is that during summer, the electrical load is low due to the lower heating load, whereas the PV generation is sufficient due to the abundant solar resource. This leads to a significant export situation. During winter, the PV generation is quite low due to the poor solar resource in Finland, whereas the electrical load is very high due to the higher heating load. Therefore, during the winter season, most of the onsite PV generation will be consumed onsite, and almost nothing will be exported.

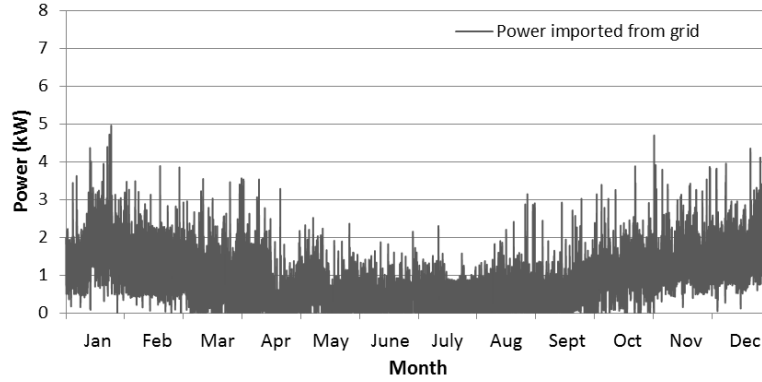


Figure 3: The recorded hourly imported electrical power from the grid

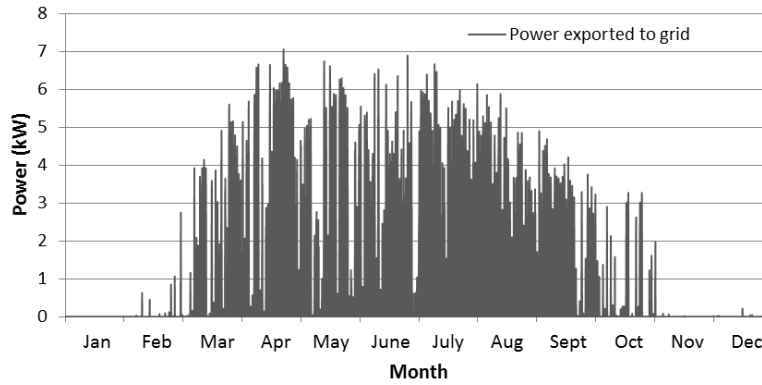


Figure 4: The recorded hourly exported electrical power to the grid

In addition, from the aforementioned hourly PV generation and the grid interactions, i.e. the hourly electrical energy imported from and exported to the electrical grid, the total electrical load can be correspondingly calculated via the following Equation (1):

$$L(t) = G(t) + I_p(t) - E_p(t) \quad (1)$$

Where the $G(t)$ is the generation after the inverter, $I_p(t)$ is the electrical power imported from the electrical grid, $E_p(t)$ is the electrical power exported from the building to the electrical grid, and $L(t)$ is the calculated total hourly electrical load. Figure 5 shows the hourly total electrical load calculated with Equation (1). The seasonal dependent characteristic can also be seen in Figure 5. During the winter season, the magnitude is mainly between 0.5 and 3 kW, while the peaks can reach 4.95 kW. During the summer season, the magnitude is mainly below 2 kW, while the

peaks can reach 3 kW. The higher electrical total load during the winter season is mainly due to the higher heating load, which stimulates a more frequent operation of the electric heat pump.

Moreover, Figure 5 also shows a duration curve for the hourly total electrical load. It can be seen from the duration curve that peaks of 3-5 kW are actually quite rare in the electrical load. The maximum peak was 4.95 kW. There was only 0.09% (8 hours) of the year when the electrical load power was higher than 4 kW. There was only 1.2% (104 hours) of the year when the electrical load power was higher than 3 kW. Moreover, the percentage of time when the electrical load power is higher than 2 kW reached 10.4% (928 hours) – thus, still a quite small percentage for 2 kW. On the other hand, we can see that the percentage of time when the electrical load power is below 1 kW reached 57.5% (5033 hours), which indicates a base load level below 1 kW in the monitored building. By checking the ranges in the duration curve, it can be noticed that actually for more than 57% of the time (4974 hours) the electrical load is between 0.2 kW and 1 kW, which can result from the base load of ventilation fans, pumps, and the regular operation of household equipment such as refrigerator, freezer, and lights. Moreover, Table 1 shows the annual measurement data for the PV generation after the inverter, the annual imported electrical energy from the electrical grid, the annual exported electrical energy to the electrical grid, and the annual total electrical load.

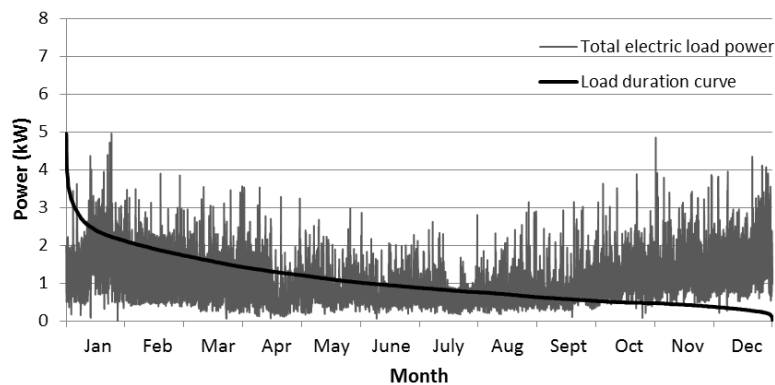


Figure 5: The hourly total electrical load and its duration curve

Table 1: The annual measured data concerning energy consumption

	<i>Annual PV generation after inverter</i>	<i>Annual electric energy imported from the electric grid</i>	<i>Annual electric energy exported to the electric grid</i>	<i>Annual total electric load</i>
<i>Total (kWh/a)</i>	6612	7786	5149	9249
<i>Per unit area (kWh/m²a)</i>	38	44	29	53

3.2 Energy Matching Analysis

From these recorded data, we can also calculate the matching indices and the grid interaction indices of the building. We use the onsite electrical energy fraction (OEF_e) and the onsite

electrical energy matching (OEMe) to analyse the matching [Cao et al. 2013]. The OEFe indicates the proportion of the total electrical load which is covered by the onsite PV generation, rather than imported from the electrical grid. The OEMe indicates the proportion of the total electrical generation which is consumed in the building and system rather than being exported to the electrical grid. There are two ways to calculate the OEFe and the OEMe:

Method 1:

$$OEFe = 1 - \frac{\int_{t_1}^{t_2} Ip(t)dt}{\int_{t_1}^{t_2} L(t)dt} \quad (2)$$

$$OEMe = 1 - \frac{\int_{t_1}^{t_2} Ep(t)dt}{\int_{t_1}^{t_2} G(t)dt} \quad (3)$$

Method 2:

$$OEFe = \frac{\int_{t_1}^{t_2} \text{Min}(L(t);G(t))dt}{\int_{t_1}^{t_2} L(t)dt} \quad (4)$$

$$OEMe = \frac{\int_{t_1}^{t_2} \text{Min}(L(t);G(t))dt}{\int_{t_1}^{t_2} G(t)dt} \quad (5)$$

Where the $L(t)$ is the electrical load power, $G(t)$ is the generation power, $Ip(t)$ is the electrical power imported from the electrical grid to the building, $Ep(t)$ is the electrical power exported from the building to the electrical grid. Method 1 is calculated by subtracting the proportion of the electrical energy which is imported from or exported to the electrical grid, whereas Method 2 is calculated by finding the minimum value between the generation and the load, which is the matched part between the generation and the load. From the illustration in Figure 6, Area I is the portion imported from the electrical grid; Area II is the portion exported to the electrical grid; Area III is the matched portion between the generation and the load. “dt” is the time-resolution used in the recording or the simulation system. If the recording system for certain building(s) includes the channels for the total PV generation (cumulative measuring system), the power imported from the electrical grid (cumulative measuring system), and the power exported to the electrical grid (cumulative measuring system), Method 1 can be used, and the results of OEFe and OEMe from Method 1 will not be influenced by the time-resolution. However, if the recording system for certain building(s) only includes the channels of the total PV generation (cumulative measuring system) and the total electrical load power (cumulative measuring system), Method 2 can be used; however, the results of OEFe and OEMe by Method 2 will be influenced by the time-resolutions, due to the averaging effect by comparing the generation and load. Moreover, it should be mentioned that when $\int_{t_1}^{t_2} L(t)dt$ is equal to zero, OEFe in Equations (2) and (4) should be equal to one, whereas when $\int_{t_1}^{t_2} G(t)dt$ is equal to zero, OEMe in Equations (3) and (5) should be equal to one.

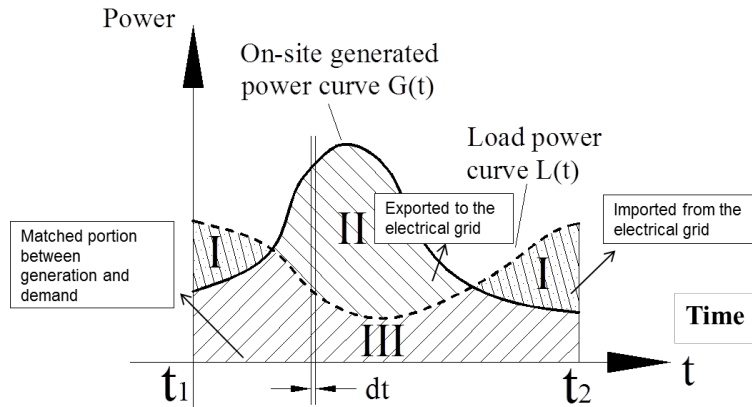


Figure 6: Illustration of the matching between the generation and the load

Figure 7 and Figure 8 show the hourly OEF_e and hourly OEM_e based on the calculation Method 1, and thus they are accurate values of the hourly OEF_e and hourly OEM_e referring to the real situation. As shown in Figure 7, the hourly OEF_e shows a very clearly seasonal-dependent characteristic, with very frequent and high levels in the summer season due to the sufficient solar resource, whereas during the winter season, the hourly OEF_e presents a generally low value with several peaks, mainly due to the higher electrical load during the winter season. This indicates that during the summer season, more onsite electrical load can be covered by the onsite PV generation, whereas during the winter season, most of the onsite electrical load cannot be covered by the onsite PV generation, i.e. it is covered by electricity imported from the electrical grid. On the other hand, as shown in Figure 8, the OEM_e are in a reversed manner, with quite high magnitude during the winter season, indicating that the PV generation is sufficiently used in the building during the winter season. However, during the summer season, the OEM_e is quite fluctuating, and reaches a minimum peak below 5%, which indicates a very poor summer self-utilization for the onsite PV generation, i.e. a large amount of PV generation is exported to the electrical grid.

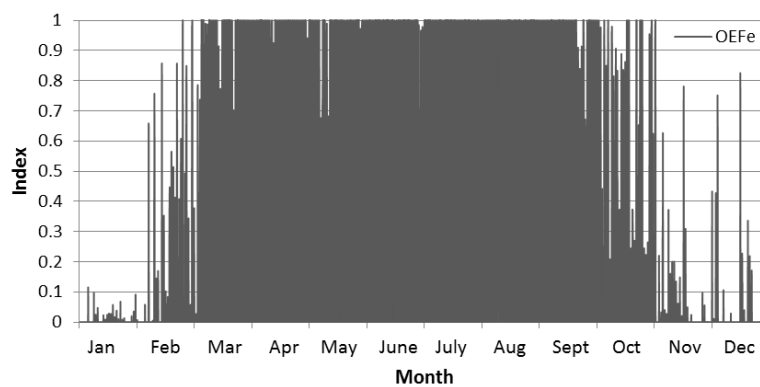


Figure 7: The hourly OEF_e calculated with Equation (2) in Method 1

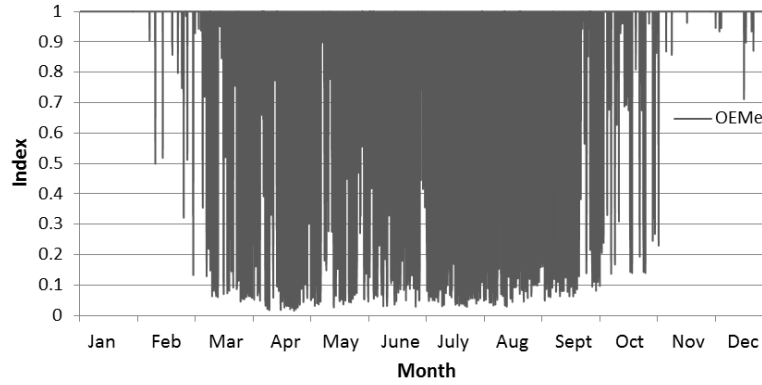


Figure 8: The hourly OEMe calculated with Equation (3) in Method 1

Table 2 presents the annual OEFe and annual OEMe with different calculation methods and time-resolutions. It can be found that with Method 1, the annual OEFe and OEMe are 15.8% and 22.1%, respectively, which indicates a quite poor matching capability. However, with the calculation Method 2, it is found that the results are overestimated by the coarser resolutions. Under the 1-hr resolution with Method 2, the annual OEFe and OEMe are 17.5% and 24.5%, respectively. Under the 1-day resolution with Method 2, the annual OEFe and OEMe are 38.6% and 54.0%, respectively. Under the 1-month resolution with Method 2, the annual OEFe and OEMe are 44.0% and 61.6%, respectively. Therefore, with a coarser resolution, due to the averaging effect by comparing the generation and load, the matching capability is overestimated. This kind of averaging error normally happens in the numerical simulations, when it is impossible to input a real high-resolution (such as 1-min or 1-s based resolution) weather, electrical device, generation, and load data [Cao and Sirén, 2014]. In simulations, normally a coarser resolution such as 1 hr is used. Another situation which will lead to the error in Method 2 is when the recording channels for certain buildings are limited to the total electrical generation (by cumulative measuring system) and total load data (by cumulative measuring system). Furthermore, it can be that Method 2 with 1-hr resolution is not quite deviated from the accurate results by Method 1. However, if the generation level is quite different from the existing system, the error can be quite different. We should conduct more research for different high-resolution generation and load patterns.

Table 2: The annual OEFe and annual OEMe based on different resolutions and calculation methods

Resolution Indicator				
		1 hour	1 day	1 month
Annual OEFe	Method 1	16%	16%	16%
Annual OEMe	Method 1	22%	22%	22%
Annual OEFe	Method 2	17%	39%	44%
Annual OEMe	Method 2	24%	54%	62%

With Equation (6) [Salom et al. 2014], the normalized variable for the net exported energy $\overline{ne(t)}$ for the building can be calculated as

$$\overline{ne(t)} = \frac{Ep(t)-Ip(t)}{Edes} \quad (6)$$

It represents the grid interactions of the zero-energy building. $Edes$ is the designed capacity for the grid interactions, and $Ep(t)$ and $Ip(t)$ are the exported and imported power to/from the electrical grid, respectively. In this study, $Edes$ is assumed to be 10 kW. Figure 9 presents the hourly normalized net export energy curve. It can be seen in the figure that during the summer season a significant amount of on-site generation is exported. The peak normalized net exported power can reach more than 60% of the designed capacity of grid interactions. However, during the winter season, the net exported energy shows a prevailing negative value due to the import of the electricity from the electrical grid. With Equations (7) and (8), we can define the peak power generation indicator and the peak power load indicator, which indicate the utilization ratio of the designed capacity for the grid connection by the peak generation and by the peak load, respectively:

$$\overline{G(t)} = \frac{Max(G(t))}{Edes} \quad (7)$$

$$\overline{L(t)} = \frac{Max(L(t))}{Edes} \quad (8)$$

According to the measured data, the peak power generation indicator is 73%, while the peak power load indicator is 50%. This means that the peak power generation can account for 73% of the designed capacity of the grid connection, whereas the peak load can account for 50% of the designed capacity of the grid connection.

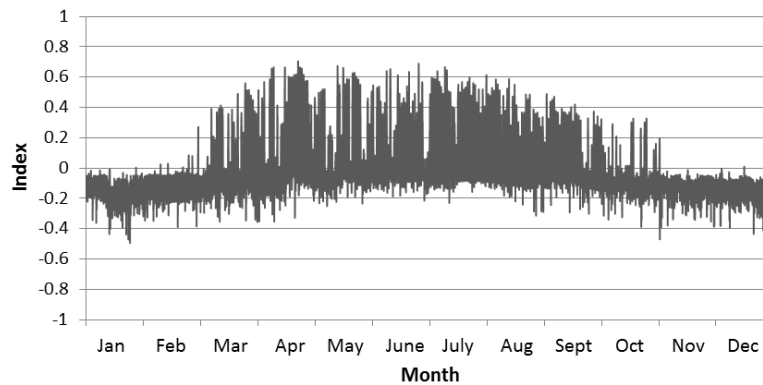


Figure 9: The normalized hourly net exported energy

4. Conclusions

Villa ISOVER[®] is a building conceived by ISOVER[®] and Fortum[®] to test the performance of a zero-energy building and its interaction with the electrical grid. It is a single-family zero-energy house built for the Housing Fair 2013. The building's energy systems have been metered, offering the opportunity to study the energy consumption and production in some detail. According to the measurement data, the annual net direct energy consumption of this building in

2014 is 15 kWh/m²a, which is thus, strictly speaking, a nearly zero-energy building. Through the analysis of the measured data, a set of conclusions have been reached:

1. The PV generation shows quite significant seasonal dependent characteristics. The peak PV generation during the summer season is higher than 7 kW, whereas during the winter season the peak has a magnitude below 1 kW.
2. The electrical load is also dependent on the season, but shows a reversed behaviour: it peaks at around 5 kW during the winter season due to the frequent operation of the GSHP and AHU heating system, but it peaks at only around 3 kW during the summer season.
3. The contrasting behaviour between PV generation and electrical load leads to a quite poor annual OEFe at 16% and annual OEMe at 22%; these indicators are seasonal-dependant, as well.
4. Coarser time-resolutions may lead to overestimations of the matching capability depending on the measurement and calculation methods. In this case study, the matching results seem to be satisfactory with the hourly resolution but not with the daily and monthly resolutions.
5. The recorded imported and the exported power from/to the electrical grid show a seasonal-dependent characteristic, with higher export and lower import during the summer season compared to those during the winter season.
6. Under the assumption that the designed capacity of the grid is 10 kW, the normalized net-exported energy will peak at more than 60% in the summer season, whereas it has a negative peak below -40% in the winter season.

To summarize and conclude, it is not only meaningful to achieve the zero-energy balance during a pre-defined duration of time, but also to maximize the energy matching of the building's own generation with its demand and minimize its exerted impact on the grids.

Acknowledgements

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How can sustainability issues be considered in the public procurement process?

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Abstract

Sustainability has become a key issue in the construction industry. Currently most of decisions on awarding public building contracts are usually based on the lowest bid. The awarding authorities do not always consider quality indicators such as technical value, energy performance, environmental issues etc. Nonetheless, a holistic consideration of sustainability aspects in the tendering and awarding stage has not yet been implemented to a sufficient extent. This paper provides an overview of the current public procurement situation and emphasises the need for considering sustainability aspects within the range of selection and award criteria in the tendering procedure in order to improve the life cycle quality of building projects. Consequently requirements for the design of selection and awarding criteria are presented, with a particular focus on social, economic and environmental aspects. A part of their characteristics are based on comparability and applicability to existing building certification systems. With respect to legal boundaries, relevant frameworks will also be examined by outlining the options for the national implementation of the directive on public procurement (Directive 2014/24/EU), as proposed in the Austrian federal procurement law. However criteria are presented, regarding the technical requirements on the one hand and the relevant suitability of the bidders on the other hand. Based on a literature review on sustainable public procurement, this paper contributes to the question what kind of sustainable issues can be used and in what way to support the awarding of construction contracts, not only based on the lowest price. Therefore it is investigated, how awarding and selection criteria can influence the procurement decision. Furthermore in this context also the weighting of such criteria is important, that these aspects are contributing to a holistic approach in terms of an integrated project delivery. Overall, this paper should create a better understanding on how sustainability issues can be considered in the procurement process, whilst raising awareness for the need of an integrated project delivery. However this should help to improve the effective utilisation of production factors towards a life cycle orientated holistic approach.

Keywords: Sustainable Procurement, Selection & Awarding Criteria, Performance-based Approach, Integrated Project Delivery

1. Introduction

Fighting climate change is one of our main contemporary tasks. The United Nations stated 17 post 2015 sustainable development goals (United Nations, 2015) to adopt ‘The 2030 Agenda for Sustainable Development’. Therefore goal number 7 affordable and clean energy, number 9 industry innovation and infrastructure along with goal number 11 sustainable cities and communities and the overall target of goal number 13 on climate action are further related to construction activities. Approximately 40 % of the global energy use is related to buildings as well as 50 % of the resource consumption is linked to construction activities (UNEP SBCI, 2003). Therefore the contribution of construction industry, to reach these sustainable development goals is very crucial. Considering these issues it becomes obvious, they can only be seen from a systems perspective, regarding all their interactions. Which means focusing on single aspects can help, but only to a limited extent. Consequently an overall integrated approach is needed to reach a sustainable development. Additionally this would benefit from synergies as well as cost savings and spillover effects. Based on integrated policies, the procurement process sets up legal boundaries for developing a construction project. Contributing towards a holistic life cycle orientated approach, key aspects of an integrated project delivery have to be focused and taken into account. In the following the procurement process and its influence towards a more performance-based approach, which is necessary to overcome current obstacles, is going to be considered.

2. Public Procurement

The procurement process influences the construction project in many different ways. Beyond its significance in terms of construction management and economics, the legal relevance of this key factors are equally important. Currently a strong focus is just on the economic aspects especially on the initial costs, neglecting follow up and utilisation expanses. Based on the market share of public procurement, this indicates a good starting point for implementing a paradigm change towards a more life cycle orientated approach. Moreover the procurement process influences both the quality of individual processes, the planning workflow and the overall quality of the project, as well as the number of construction process disruptions and thus the amount of additional costs claimed.

2.1 Policies and legal frameworks

Over the last few years several initiatives targeting the public responsibility have been published and comprehensive research was undertaken to improve procurement performance. Based on European and national initiatives, there are policies proposed to focus on additional aspects during the tendering procedure. One of the main commitments has been stated within in the white paper on public procurement in the EU and COM 96 (583) final and COM 98 (143) final. This was continued by the COM(2001) 274 with a focus on “*Commission interpretative communication on the Community law applicable to public procurement and the possibilities for integrating environmental considerations into public procurement*”. This resulted in the

European directive 2004/18/EC supporting the awarding of contracts based on the most economically advantageous tender.

Based on the goals of a sustainable development this shows the need to set up criteria to support the decision-making process focusing on a life cycle performance. Therefore in a first step the European directive 2014/24/EU enables tendering decisions based on a more life cycle orientated perspective.

2.2 Green and sustainable public procurement

In the past few years, strategies are designed supporting a sustainable development on international and national level. In this context, green public procurement (GPP) indicates the attempts of public authorities to procure goods services and works e.g. buildings with reduced environmental impacts over their life cycle. Therefore the work of the CEN/TC 350 on sustainability of construction works delivers a set of indicators, to assess environmental impacts of buildings cf. EN 15978. However GPP mainly focuses just on environmental aspects of products and services, whereas sustainable public procurement widens up the focus targeting all three pillars of sustainable development (ecological, economical and social issues).

Targeting a holistic approach, these aspects need to be considered in the tendering procedure, therefore criteria are needed to be defined taking into account these goals applied and linked to the particular building project. To enable a proper decision-making process, their objectives need to be defined at the beginning of the procurement process. Consequently they need to be stated clearly in the call for tenders especially how they are going to be assessed during the evaluation of tenders and also their weighting needs to be determined, to guarantee a transparent tendering procedure and therefore supporting an integrated project delivery.

3. Methodology

Based on the investigation of the current state on public procurement, requirements towards more sustainable procurement decisions are assessed. Therefore the basis of this contribution is an on-going research project dealing with the following selected research questions (RQ):

- RQ1: How can sustainability be considered in the procurement of construction works?
- RQ2: Which aspects can be used, to define such criteria?
- RQ3: What are the requirements for such criteria?

In order to consider the requirements for sustainability aspects, which can be used in the procurement of construction works, it is necessary to make a structural analysis of current approaches. Based on a comprehensive literature review (Wall and Hofstadler, 2016) the recent strategies and developments over the last few years in green and sustainable procurement have been assessed. Following a holistic approach, considering environmental, social and economic aspects of sustainability a set of indicators in terms of a multi criteria analysis is needed (Zavadska and Antucheviciene, 2006). Hence a key component of analysing the procurement

system is examining the perspectives and approaches of multiple stakeholders of construction projects, to identify on which information and what criteria their decision-making process is based on. Following the hermeneutic circle, the findings of these investigations are reworked and therefore procurement stages as well as tender elements are analysed based on legal frameworks to identify possibilities towards a more performance-based approach. The requirements presented in the current contribution are the basis for an expert survey to gain empirical data for future needs and designs of such criteria.

4. Current situation of public procurement

Construction industry is characterized through highly competitive markets. Furthermore mainly the initial costs are taken into account for awarding the tenders. As a result service and quality is suffering as companies are forced to cut costs in order to survive these harsh conditions. To challenge these circumstances public procurement therefore has to make use of its crucial influence based on the market share and promoting a life-cycle-orientated and sustainable development. Using the ‘most economically advantageous’ tender could be helpful, for considering additional criteria, which are focusing more on a holistic approach. As illustrated in fig.1 there are several requirements on sustainable construction, which can be linked to the rise of building certification schemes (e.g. BREEAM, DGNB, LEED) on the left side and on the right side to normative requirements especially for the building products.

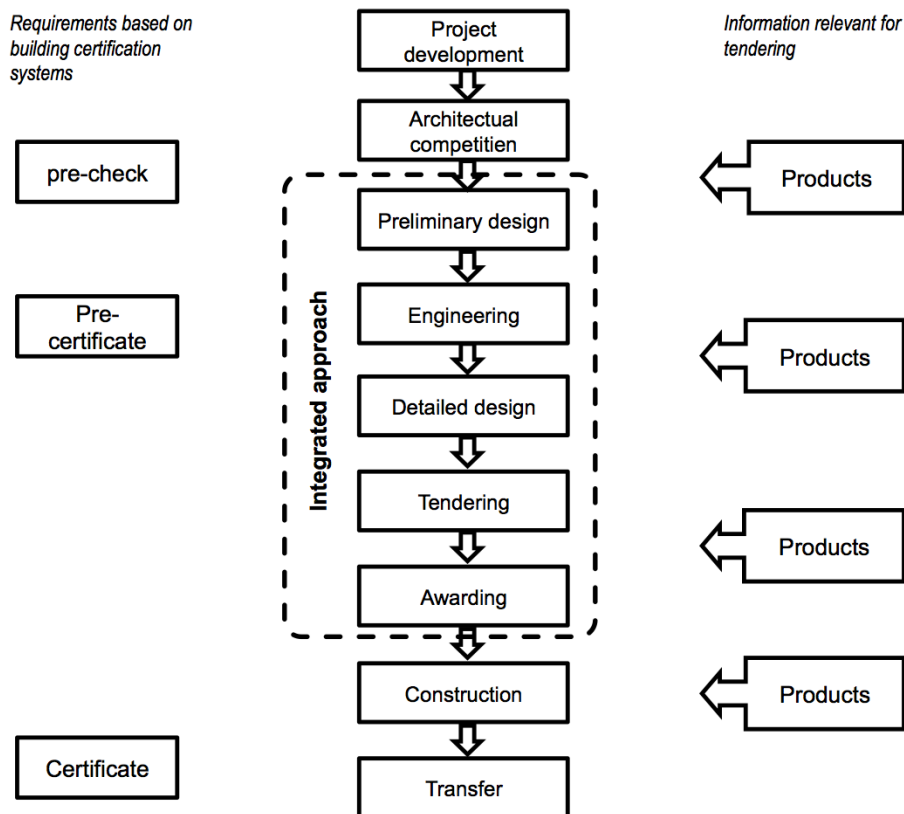


Figure 1: Construction project stages with requirements based on building certification systems and product-based information regarding the procurement and tendering decision cf. Wall 2016

Over the last few years, in terms of sustainable construction targets building certification systems are seen as a suited tool to consider these aspects in a measurable way. Otherwise more information on the environmental aspects and properties of building products are available. Various databases (e.g. baubook in Austria or WECOBIS and ökobaudat in Germany) are providing information on environmental impacts of different construction products and building components. Based on the methodology of life cycle assessment according to EN ISO 14040 et seq. their ecological performance can be determined. This information can be communicated with the help of environmental product declarations (EPDs), representing a suitable format to notify ecological aspects of products and building components in a standardized way. They can support decision-making in early planning stages. Nonetheless different building concepts can be compared in terms of their environmental aspects. Following their standardized information, they can also be used in the procurement process to indicate the consideration of sustainability aspects and can be seen as a good method for verification and quality management during the construction phase. Another important issue is the weighting of additional quality aspects to base the tendering decision on. A case study in Finland, Sweden and Denmark (Parikka-Alhola et al, 2006) investigated a range from 5-20 % for the quantification of additional aspects in the tendering procedure. Based on the chosen weighting it is not always obvious, if they can influence the final awarding decision.

One of the main problems of construction contracts is, that they are related to different spheres, legal boundaries and are influencing construction management and information flows. In fig.1 the sequential workflow is indicated by the single project stages. Targeting a life cycle orientated approach, all these conditions need to be evaluated and properly assessed to describe a construction contract.

Overall, decision support is demanded, in terms of organized efforts to produce, disseminate and facilitate the use of data and information to improve tendering decisions towards a life cycle consideration. This leads to the recognition, that decision processes are at least as important as decision itself on which the tender is going to be based on. To improve the decision-making process towards a holistic approach, a research focus is on how awarding decisions are made and what affects them. Therefore policy makers need insight on how current barriers (like quality of project development, organisational obstacles) can be removed through common-sense steps such as simplifying communications and making choices more clear. The challenge is to create awareness by stakeholders in different areas (environmental management and policy decision-making). In this context besides the ecological issues especially the processes in the design and engineering stage need to be considered more comprehensively. The interactions on product level and the overall performance of buildings are strongly influenced by planning processes. A life cycle optimized building can only be achieved through integrated planning processes providing the basis for a successful combination of the production factors. Focusing on such an approach, the question rises how can a sustainable performance be defined and considered during the procurement and tendering stage. How can such issues be measured and controlled? How and to what extend can they be implemented into the procurement stage? Especially if focusing on performance-based aspects, which are highly related to individual

experiences and knowledge. How can such information be taken into account to base the tendering decision on?

Therefore requirements towards a more performance-based approach are presented in the following chapter, which can be seen as possible key performance indicators influencing the procurement process among the life cycle of a building.

5. Requirements towards a performance-based approach

Integrated project delivery is used, to identify the most suitable solution for a problem also considering its life cycle performance. Following this approach a more holistic thinking is triggered in construction industry. The overall aim is to enable and support competition based on sustainable innovations. In this context the procurement process is identified as a very crucial stage in the overall project delivery, because the influence at this stage is suited best, to implement a more life cycle based focus, which needs to be based on quality of related processes. Process quality is defined through the planning and construction processes as well as preparing the commissioning of buildings. Thus performance and quality of the building is significantly influenced at the early project stages. Consequently a more integrated and cooperative model is used to focus on the life cycle quality and responsibility aiming at the project development (AIA 2007).

Therefore a strong focus is not only on product level, especially the process level is addressed. Assessing the life cycle of products as well as completed buildings, their quality is acknowledged but the processes, which have been necessary to achieve such a performance, are often neglected and ignored. However they are contributing towards a more systematic decision-making process, which leads to a better overall project performance. Therefore especially the related planning and project management processes need to be targeted.

Supporting a quality-based (architectural) competition helps to promote innovative solutions and a more life-cycle-orientated project development already in early planning stages. The common project workflow is chronologically and sequentially structured, each task is processed, after the previous one is finished. This leads to a strict planning and working schedule. But in times of increasing complexity of building structures as well as the demand for advanced integrated building systems, each of the stages are linked together, based on contemporary requirements of planning and implementing such systems. For a comprehensive planning and processing of these tasks integrated information is needed. Consequently a more integral project workflow including all participants and involved stakeholders towards a holistic optimization of the project is targeted. Especially the process-related aspects need to be emphasized and should already be considered at the procurement stage of construction projects.

A performance-based procurement can only be achieved if the chosen issues for tendering can be planned, defined measured and justified to comparable for the evaluation of the different tenders. Therefore criteria are needed serving as indicators, index numbers and measureable values. Key figures can provide information based on facts. Indicators are describing qualitative

and quantitative relationships, which cannot be measured directly. For measuring process quality indicators need to be identified in accordance to the particular project stages and tasks. In the following fig. 2 several aspects towards a performance-based procurement are listed.

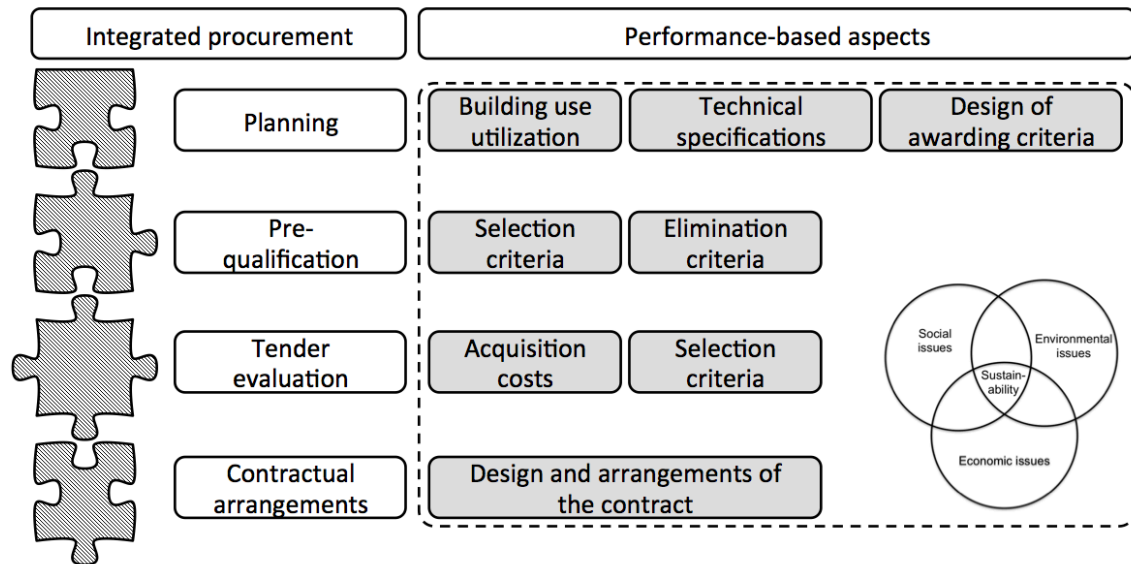


Figure 2: Aspects of an integrated procurement following KfW (2014)

Quality and qualification of the contractors is highly relevant for an integrated project delivery process and therefore needs to be examined. Their suitability and handling by project managers show a significant contribution towards a successful project realisation as mentioned by Hwang and Ng (2013). This correlation has also been stated by the Austrian court of audit in its statement on public financial control cf. ACA (2006). Additionally the ECJ confirmed in Case C-601/13 Ambisig 03/26/2015, using a criterion which takes into consideration the composition of the team, the experience, the academic and professional background of the employees, for enabling an evaluation of teams especially for the performance of the contract.

Another aspect seems to be the corporate philosophy of the contractor, related to the organizational issues of the project team, in terms of their company culture and how projects are realised. These aspects are very crucial for an integrated project development because it leads to the communication culture and information sharing among project participants for creating a cooperative climate between clients and contractors. This underlines quality standards and performance-based aspects of project management and project delivery. Internal project structures and organizational behaviour towards clients and subcontractors are highlighted based on the principles of the corporate philosophy of the enterprise (IG Lebenszyklus, 2015). This includes employment relationship, staffing schedule, and a proactive and solution-orientated working approach on the building project. In this context also the internal personal contribution can be seen as a crucial aspect towards a high quality performance on the construction site. This is discussed at the moment in Austria with the 'fair procurement initiative' focusing on the quality and qualification of employees influencing the later project performance. Performance-based tendering decision can therefore include expert interviews with key persons discussing

their problem solving capacities and to assess their qualification and applicability for the project specific requirements.

Quality management and documentation during the construction period leads to an evidence-based knowledge management system, which considers all the information flows from the beginning of the planning stages to the construction stages, generating information to improve the commissioning phase of the building with its building technologies as a basis for monitoring activities and facility management tasks later on (influencing the total sustainable performance of a building). In this context lean thinking can be applied. This means information on what to do, when, in what quality and based on which conditions to guarantee optimal information flow as well as operational management. This can be used as part of selection criteria on prequalification see fig. 2.

Suitable criteria are used to specify the quality of the contractor to perform a specific task and how to handle a certain project. Therefore the technical competences can be targeted, which means professional entitlement but also financial and economic performance criteria that are linked to the specific project and/or construction works. For an easier verification of such issues, there are platforms (e.g. ANKÖ, PQ-VOB) providing information on performance records of contractors.

Finally the weighting is a very crucial point, because in the call for tenders the importance of such selection and awarding criteria has to be announced, that there are no spurious aspects, which are not that relevant for the final tendering decision. The awarding should be based on the technical and economically advantageous tender. Therefore usually a jury is necessary to support the awarding process. Especially if judging functional construction concepts on behalf of safety and environmental performance aspects. The awarding committee can assess intended workflow processes and problem-solving skills of the involved key persons with standardised interviews. Therefore the jury members should be involved right from the beginning on to define specific criteria in the call for tender and providing a consistent consideration of these issues and their weighting factors through tendering and awarding. This is stated e.g. by the Austrian National Committee of ITA (2014) on suggesting a procurement model for infrastructure projects. Following these suggestions the composition of the committee is crucial to gather experts from all the different backgrounds, related to the type and special requirements of the particular project. It is crucial for a successful project delivery to concentrate their competences and background knowledge considering all the clients and users requirements.

6. Discussion

Facing climate change public procurement is seen as a suitable tool to apply innovation policy. In this context current backward thinking in terms of focusing just on the initial costs combined with organisational obstacles need to be changed. A special focus is on the type of contract, showing a higher likeliness for design-built contracts considering green innovations cf. Monahan et al (2014). Currently there are still several barriers to sustainable public procurement. In their studies Uyarra et al (2014) reported a lack of interaction of procuring

organisations and low competences of procurers resulting in difficulties in negotiating risk management issues due to the higher requirements of the building projects. Considering life cycle aspects, the procuring organisation has to be aware about their future needs and usage requirements. The determination of needs is often barely conducted, accompanied by insufficient understanding creating barriers to innovative sustainable solutions. If the procurer does not know what he is looking for it's not easy to set up functional specification and awarding criteria to evaluate the tenders for the most innovative (best suited) solutions. Despite numerous political statements and commitments towards sustainable construction, the state of the art in awarding public building contracts is mainly related to the lowest price. In the end only the building qualities are considered and visible, the processes, which have been necessary to undertake, are not seen anymore. Unfortunately they have a crucial impact on the success of the project. Therefore the goal is to identify the key-processes, which are needed to achieve a high performance building. Towards a more life cycle orientated consideration of buildings, a holistic approach is needed and has to be integrated and interdisciplinary designed. A crucial aspect in this context relays on the early project development stages that are of fundamental importance towards the final building performance. The current situation is more linked to single normative solutions, which are recognized more unsatisfying as also mentioned in the final report on major building projects (BMVI, 2015). Therefore a cultural change is suggested, towards more cooperative project workflow characterised with comprehensive information exchange to focus on the project details and contents. This could help to overcome incomplete information and fragmented knowledge management. Towards a life cycle orientated building process, these information need to be considered during the procurement process. Overcoming the sequential process workflow, consequently a more performance-orientated approach is suggested like Uttam et al. (2014). Based on the literature review (Wall and Hofstadler 2016) a lack of interaction within the procuring organizations and the contractors has been identified, which causes different understanding and a reduced and disrupted information flow. To overcome these obstacles fundamental elements for enabling cooperative procurement have to be promoted. In fig. 3 the requirements towards a more performance-orientated approach are illustrated following Owen et al. (2010).

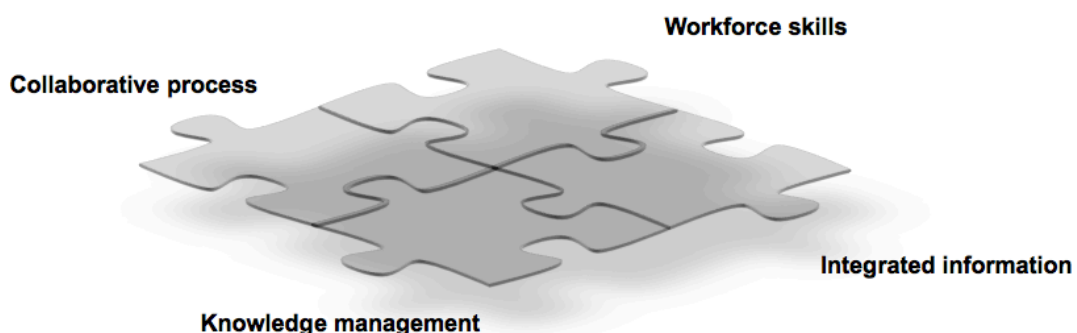


Figure 3: Requirements towards a more performance-orientated approach

Collaborative processes, workforce skills integrated information and knowledge management are the requirements to overcome silo mentalities combined with cultural prevail and document-based information exchange. Bresnen and Marshall (2000) stated the importance of partnering for improving construction performance directly, by promoting stronger client and contractor interaction. To reach these conditions, organisational and cultural change is necessary, especially in context of implementing sustainability aspects and focusing on the life cycle of a building. Incorporating environmental, economical and socio-functional issues into project delivery, this will help to consider a more comprehensive life cycle perspective, and enabling newer greener technologies and fostering innovative developments, this approach is supported by Hwang and Ng (2013). In their work they investigated the contribution of project managers to green construction projects, they stated the need for knowledge and skills to deal with the increased requirements of sustainable building projects. Eriksson and Westerberg (2011) proposed a holistic procurement framework, dealing with a broad range of factors related to procurement and showed, that relationships among clients and contractors are influencing project performance (e.g. trust and commitment among project partners). Similar approaches are introduced e.g. by IG Lebenszyklus (2015), setting up requirements towards a cooperative project culture pushing a performance-based approach providing optimal project conditions for an integrated project delivery. Evidence is provided by taking care of the clients' definition of requirements, setting a focus on project management and project workflow. Additionally keeping in mind legal and financial boundaries to deal with these issues in terms of risk management.

Currently there are several initiatives focusing more on changing the procurement model towards the most economically advantageous tender. They are targeting the project itself and with the help of a performance-orientated procurement a holistic life cycle optimization can be achieved, because the interdisciplinary organizational structures are more and more important. This demands a more cooperative project delivery, which cannot be reached with common sequential waterfall approaches.

Focusing on the implementation of such a performance-based approach, it can be linked to future developments of procurement models like cooperative procurement and competitive dialog procedure. Therefore legal requirements are important focusing on the type of procurement and the chosen framework (e.g. project is awarded on a lump-sum basis or as a total). However the legal procurement framework conditions need to be considered. This highlights equal and uniform treatment of all bidders and a transparent awarding decision, which is based on expert knowledge. Therefore the used criteria have to be defined, measurable and assessable regarding to various sustainable aspects of building performances.

7. Conclusions

This contribution underlines the need for a cooperative procurement approach to achieve the goals of a sustainable development in the construction sector. Answering the research questions stated at the beginning, RQ1 a consideration of the whole life cycle of a building or construction project can only be realised with the help of integrated design and delivery solutions. Therefore

life cycle orientated issues have to be used for formulating criteria, which can be used for a performance-based cooperative tendering procedure. They can be divided into selection and prequalification criteria to support these processes (RQ2). The requirements for such criteria (RQ3) are based on the building utilisation, technical specifications, also economical performance issues and the overall organisational structures, which are linked to the contract. This procedure is all about information management, contents and knowledge need to be processed, transferred and communicated among the involved stakeholders. Consequently tools like building information modeling can support these ambitions and providing a platform for exchange and a basic ideal surrounding for improved workflows to reach the goals of an integrated design and project delivery.

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Built environment and its parts: towards an integrated study of the construction as a system using an evolving technological knowledge

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Abstract

To consider the built environment as a single system is in contrast with the tendency towards specialization and analysis. Multiple changes are now taking place simultaneously in the planning process, the construction techniques, the organization of a building site, the production of materials and the technical information. All this is driven by a progressive specialization of knowledge and an increasingly important role of data and tools coming from different scientific apparatus. The richness of building methods is always evolving to meet very different requirements in extremely varied conditions and environments. This, however, makes the understanding of the construction and the environment as a ‘system’ difficult and, consequently, all of the various elements that must contribute to forming the system. All this is in a scenario dominated by “Big Data” and computerized processing of information that seem to make natural language completely inappropriate to the task. In this situation and in our role as professors involved in the training of future professionals, we are committed to defining a method for dealing with the processing of information relating to construction within a system that permits operating at the level of analytical details without losing the connection to the system in general.

The study presented here is based on the use of cognitive maps to represent the parts as a general whole of the construction as a system, through a coded breakdown of sentences that convey information. Considering the need to maintain all the usual forms that architects use in their design work, as well as relying on known and familiar examples of constructions, we link basic elementary concepts to the most widespread architectural journalism. Essentially, examples of solutions which refer to parts of the construction system empower designers to grasp the essential function of the parts to reach a complete and organic understanding of them in relation to the system itself. Starting from the five main themes that compose the construction system (ground anchoring, structure, enclosure, roofing and systems), we synthesized in a few booklets the basic information necessary for an architect to understand the construction and its parts as a ‘system’.

Keywords: construction system, innovation, knowledge, concept map, information

1. Introduction: transforming information while maintaining the usual forms as much as possible

To study the construction as a system, it is not enough to know the various elements that compose it; obviously, it is equally important to know their connections, otherwise the operation of the system is not comprehensible. Today, however, technological knowledge usually relies on publications illustrating long list of different types of building elements, distinguished, for example, by materials, forms or dimensions (i.e.: Di Chiara, 1990, Zaffagnini, 1992). Even, the most recent overviews of the architectural elements, such as the one presented at the Venice Biennial exhibition in 2014, ignored their organization as a system (Koolhaas, 2014).

Construction as a system is considered mainly when management and engineering problems, such as automation, are faced. It happens only when new building systems are introduced, but it almost never happens when we are dealing with traditional techniques (Van de Sompel, 2004). Objectively, we cannot deny that a great difficulty exists to entail general aspects when it's necessary to deepen the analysis and study of details.

For this reason, reminding that technological knowledge transmission has always been basically visual (i.e., Encyclopédie by Diderot and d'Alembert), in this study, we tried to find out graphic forms of its presentation according to its systemic nature. Therefore, we found out a corresponding form to those purposes in the methods proposed by Novak and Gowin (1984). Conceptual maps allow a visualization of knowledge in which it's possible to go deep without losing sight of the system essence as a whole (Figure 1).

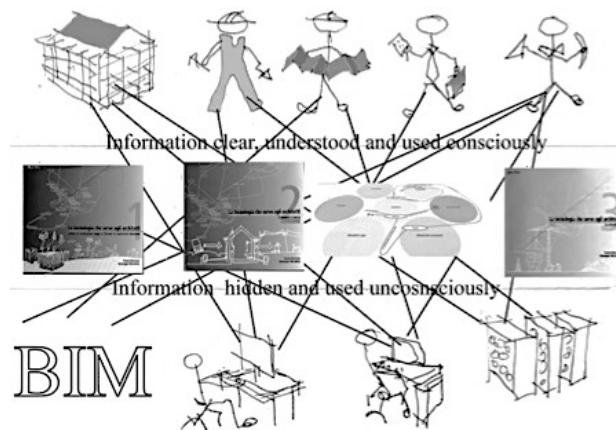


Figure 1: Fundamental strategy: connecting all elements

We applied that method taking care that the graphic forms were similar to those commonly used by the professionals of the sector.

The research presented here deals with a new way of communicating technological knowledge; through a series of steps, the study demonstrates how we succeeded in maintaining traditional forms.

In order for this communication to be made easy to understand, we have tried to maintain a form very similar to that which characterizes traditional communications, i.e. the forms of representation and content commonly used in the industry.

To understand both the theoretical principles that have guided the research and the underlying structure of the presentation of technological knowledge in a new form, it is useful to follow the studied transformation process.

2. Transformation process

2.1 Completing the transmitted information

The traditional form of communication used by industry professionals when attempting to transmit information on the building system prefers to present the study of details to present the parts which make up the represented element.

This description is generally incomplete because it only describes the part or parts, while ignoring the reasons underlying that choice, or at least not defining the way in which the represented element was or is planned to be made (Figure 2).

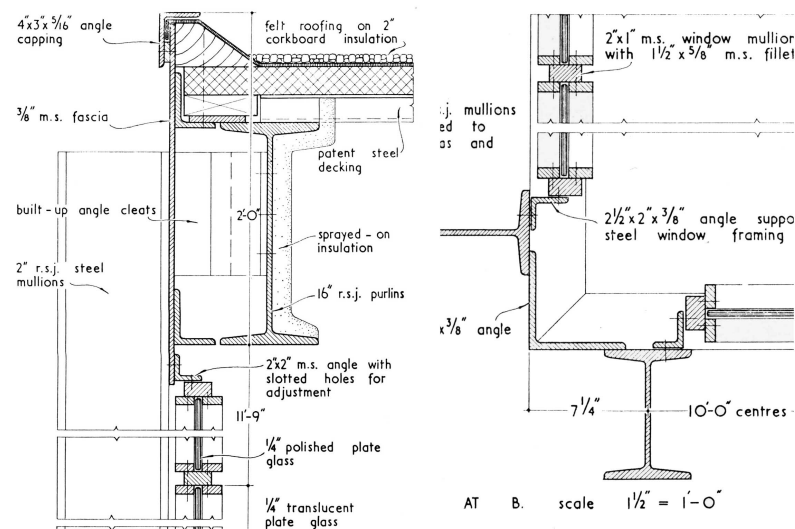


Figure 2: Details and traditional captions

For this reason, a first improvement on the ‘traditional’ type of communication may be achieved by introducing information concerning not only ‘what’ is being talked about, but also ‘why’ it is there and ‘how’ one intends to make it or has made it.

We studied this transformation of information in a way intended to maintain as much as possible the characteristics of understandability of the traditional forms of communicating technological

information to make them more comprehensive and organized.

2.2 Linking the information contained in the traditional forms of communication with the unified classifications

The study of technologies entrusted to the presentation of particular examples of buildings or specific projects is inevitably very partial. Only in specialized books, albeit theoretical, can one trace the different technological solutions for the building elements of the architecture.

To obtain the same result, no longer with a theoretical presentation but through the study of a series of examples, the descriptions must be given such as to make it possible to compare alternative solutions presented in other examples, framing particular problems within more general ones.

This is possible if, in the analysis of the example, a direct reference is made to some order of classification of the different solutions (Figure 3).

A. COSA		B. PERCHÉ		C. COME	
ST/	SISTEMA TECNOLOGICO	SIC/	REQUISITI RELATIVI ALLA CLASSE ESIGENZIALE 'SICUREZZA'	LAV/	LAVORI
ST/1	STRUTTURA PORTANTE	SIC/1	di stabilità	LAV/1	lavori edili (in generale)
ST/1.1	struttura di fondazione	SIC/2	di protezione da azioni	LAV/2	demolizioni e rimozioni
ST/1.2	struttura di elevazione	SIC/3	di sicurezza elettrica	LAV/3	terre, materiali di scavo
ST/1.3	struttura di contenimento	SIC/4	di sicurezza alle folgorazioni	LAV/4	conglomerati
ST/1.4	supporto diagonale	SIC/5	di sicurezza al fuoco	LAV/5	laterizi, blocchetti
ST/1.5	assicelle	SIC/6	alle manovre	LAV/6	componenti prefabbricati pesanti
		SIC/7	di sicurezza d'utenza	LAV/7	profilati, barre
		SIC/8	di tenuta	LAV/8	tubi
				LAV/9	cavi, reti
				LAV/10	retti spessi, materassini
				LAV/11	teli flessibili (per impermeabilizzazioni, barriere al vapore, strati antridrace)
ST/2	CHIUSURA	BEN/	REQUISITI RELATIVI ALLA CLASSE ESIGENZIALE 'BENESSERE'	LAV/12	fogli malleabili
ST/2.1	chiusura verticale	BEN/1	termici e igrometrici	LAV/13	lastre a sovrapposizione, tegole
ST/2.2	chiusura orizzontale inferiore	BEN/2	acustici	LAV/14	lastre piane, pannelli
ST/2.3	chiusura orizzontale su spazi esterni	BEN/3	visivi	LAV/15	piastrelle, mattonelle, lastre
ST/2.4	chiusura superiore	BEN/4	tattili	LAV/16	teli flessibili (per finiture interne)
ST/2.5	chiusura inclinata	BEN/5	respiratorio-olfattivo	LAV/17	materiali fluidi
ST/2.6	pavimentazione			LAV/18	piante, semi
ST/2.7	finitura	FRU/	REQUISITI RELATIVI ALLA CLASSE ESIGENZIALE 'FRUIBILITÀ'	LAV/19	componenti prefabbricati complessi
ST/2.8		FRU/1	adattabilità degli spazi	LAV/20	materiali informi
		FRU/2	adattabilità delle finiture e degli organi meccanici	LAV/21	giunti
ST/3	PARTIZIONE INTERNA			LAV/22	disponibile
ST/3.1	partizione interna verticale	ASP/	REQUISITI RELATIVI ALLA CLASSE ESIGENZIALE 'ASPETTO'	MAT/	MATERIALI
ST/3.2	partizione interna orizzontale	ASP/1	aspetto	MAT/1	MATERIALI FORMATI
ST/3.3	partizione interna inclinata	ASP/2	aspetto degli elementi tecnici	MAT/1a	pietre naturali
ST/4	PARTIZIONE ESTERNA	INTEGR/	REQUISITI RELATIVI ALLA CLASSE ESIGENZIALE 'INTEGRABILITÀ'	MAT/1b	prodotti in conglomerati
ST/4.1	partizione esterna verticale	INTEGR/1	integrabilità degli elementi tecnici	MAT/1c	materiali argillosi e ceramici
ST/4.2	partizione esterna orizzontale			MAT/1d	metalli
ST/4.3	partizione esterna inclinata	GEST/	REQUISITI RELATIVI ALLA CLASSE ESIGENZIALE 'GESTIONE'	MAT/1e	legnami
ST/5	IMPIANTO DI FORNITURA SERVIZI	GEST/1	di economia	MAT/1f	materiali organici
ST/5.1	climatizzazione	GEST/2	di manutenibilità	MAT/1g	fibre inorganiche
ST/5.2	idrosanitario	GEST/3	di funzionamento	MAT/1h	gomme, materie plastiche
ST/5.3	smaltimento liquidi			MAT/1i	retti
ST/5.4	smaltimento aeriformi	SALV/	REQUISITI RELATIVI ALLA CLASSE ESIGENZIALE 'IMPATTO AMBIENTALE'	MAT/1i	disponibile
ST/5.5	smaltimento solidi	SALV/1	salvaguardia dell'ambiente	MAT/2	MATERIALI INFORMI
ST/5.6	distribuzione gas			MAT/2a	inerti
ST/5.7	elettrico			MAT/2b	calci, cementi, malte, calcestruzzi
ST/5.8	telecomunicazioni			MAT/2c	argilla, gesso, magnesio, leganti plastici
ST/5.9	fisso di trasporto			MAT/2d	materiali bituminosi
ST/6	IMPIANTO DI SICUREZZA			MAT/2e	disponibile
ST/6.1	antincendio			MAT/3	MATERIALI FUNZIONALI
ST/6.2	messa a terra			MAT/3a	materiali per fissaggio e giunzione
ST/6.3	parafulmine			MAT/3b	protettivi e additivi
ST/6.4	antifurto e antintrusione			MAT/3c	niture e vernici
ST/7	ATTREZZATURA INTERNA			MAT/3d	materiali ausiliari
ST/8	ATTREZZATURA ESTERNA			MAT/3e	disponibile

Figure 3: The classification system, 'what', 'why' and 'how'

There are institutions and bodies for standardizing which produce coded classifications, grouping the possible construction choices that exist for each element. They also encode the requirements the elements must satisfy, and every possible processing type that may be used for executing the various building forms that the elements themselves can assume.

These classifications have been used in the descriptions/captions that we have produced to define the items that refer to ‘what’, ‘why’ and ‘how’. The technological information contained in the description was thus coded and formally linked to unified systems of classification well known to designers.

2.3 Identifying the constructive alternatives by ordering examples according to unified classifications

By assigning each element of the example to the classifications and then scrolling through these, one can find similar solutions in the same class and constructive alternatives in other classes. The finding of an example in a given class means it is possible to use it in the various examples given.

Figure 4 shows the table highlighting the location of the examples in the classification of ‘how’. There is a similar organization in the other two fundamental classifications.

It is thus possible to use these tables as indexes when searching for examples with particular characteristics (Van de Sompel, 2004).

C. COME		ESEMPI																									
LAV/	LAVORI	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	24				
LAV1	lavori edili (in generale)	6																									
LAV2	demolizioni e rimozioni	1	2	4	5	6	7	8	11	12	13	14	15	16	17	18	19	20	21	24							
LAV3	terre, materiali di scavo	25	26	27																							
LAV4	conglomerati	17	18	20	22																						
LAV5	laterizi, blocchetti	2	5	6	10	14	17	20	25	26																	
LAV6	componenti prefabbricati pesanti	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	21							
LAV7	profilati, barre	22	23	25	26	27																					
LAV8	tubi	9	14	23																							
LAV9	cavi, reti	9	10	12	15	16	19	23																			
LAV10	feltri spessi, materassini	14	19																								
LAV11	teli flessibili (per impermeabilizzazioni), barriere al vapore, strati antiradice)	6	9	12	17	19	20	23																			
LAV12	folgi malleabili	2	10	14	15	16																					
LAV13	lastre a sovrapposizione, tegole	12	19	26																							
LAV14	lastre piane, pannelli	3	6	7	8	17	18	19																			
LAV15	piastrelle, mattonelle, lastre	3	4	5	6	7	10	11	12	15	16	17	19	20	26	27											
LAV16	teli flessibili (per finiture interne)	4	9																								
LAV17	materiali fluidi	6	25	26																							
LAV18	piante, semi	1	7																								
LAV19	componenti prefabbricati complessi	4	5	9	10	11	12	15	17	19	20	21	22	23	24	25	27										
LAV20	materiali informi	14	16																								
LAV21	giunti	8	11	13	15	17	19	23	25	27																	
LAV22	disponibile																										

MAT/	MATERIALI	16	17	18	22																					
MAT/1	MATERIALI FORMATI																									
MAT/1a	pietre naturali	2	5	7	9	10	12	14	17	18	20	25														
MAT/1b	prodotti in conglomerati	18	20	22																						
MAT/1c	materiali argillosi e ceramici	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20						
MAT/1d	metalli	21	23	24	25	26	27																			
MAT/1e	legnami	4	6	7	9	12	15	21	22	27																
MAT/1f	materiali organici	9																								
MAT/1g	fibre inorganiche	4	8	9	19																					
MAT/1h	gomme, materie plastiche	5	6	8	9	12	14	15	16	17	19	20	23	26												
MAT/1i	vetri	5	10	10	11	15	15	22	22	23	26															
MAT/1l	disponibile	27																								
MAT/2	MATERIALI INFORMI																									
MAT/2a	inerti	6	9																							
MAT/2b	calci, cementi, malte, calcestruzzi	1	2	4	5	6	7	8	9	11	12	13	14	15	17	19	20	21	24	25						
MAT/2c	argilla, gesso, magnesio, leganti plastici	26	27																							
MAT/2d	materiali bituminosi	5	11	14	20																					
MAT/2e	disponibile	20																								
MAT/3	MATERIALI FUNZIONALI																									
MAT/3a	materiali per fissaggio e giunzione	12	14	16	17																					
MAT/3b	protettivi e additivi	6	9	19	26																					
MAT/3c	pitture e vernici																									
MAT/3d	materiali ausiliari	26																								
MAT/3e	disponibile																									

Figure 4: The alternatives in ‘how’

2.4 Identifying the construction problem faced by the detail analyzed.

In the ‘construction’ system, the study of a construction detail is useful for understanding the reasons for the solution in light of the problem addressed. The problem, which in general can be summarized in an intuitive form, is useful for starting the return from the particular to the general, which is necessary in order not to lose sight of the unity of the ‘construction’ system (Figure 5).

If the examples are chosen with the aim of addressing, in a certain order, the constructional problems to be studied, it is possible to present a topic using the form of rhetorical question and answer.

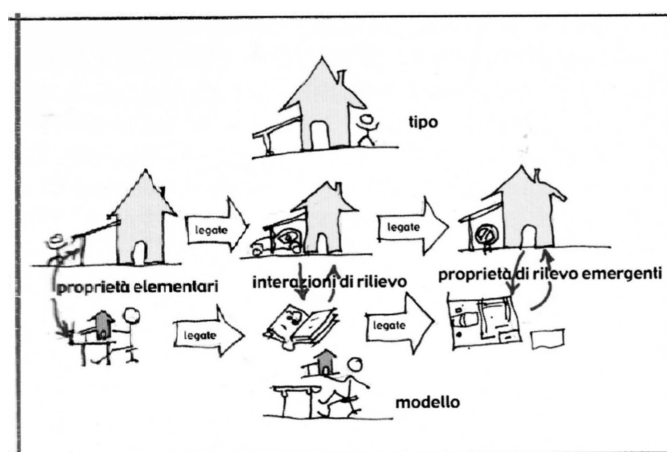


Figure 5: A synthesis process of a constructive problem

The rhetorical question and the related answer is ‘constructed’ and positioned on a concept map.

2.5 Constructing a discourse on the topic

Without disturbing the ‘systems theory’ by Ludwig von Bertalanffy, and sharing that technology as a subject is presented, for the main part, graphically, our contribution concerned the visualization of the construction system using maps.

All the problems detected in the various examples can thus build a discourse on the theme that frames the element studied in the construction system. The form given to this work comes from the application of J.D. Novak and D.B. Gowin (1984) applied pedagogical studies described in their famous work “Learning how to Learn”.

This approach led to the organization of a general and articulated explanation regarding a construction element starting with a crucial question containing some concepts, followed by a series of rhetorical questions that contained other concepts explained by the subsequent relative answer (Figure 6).

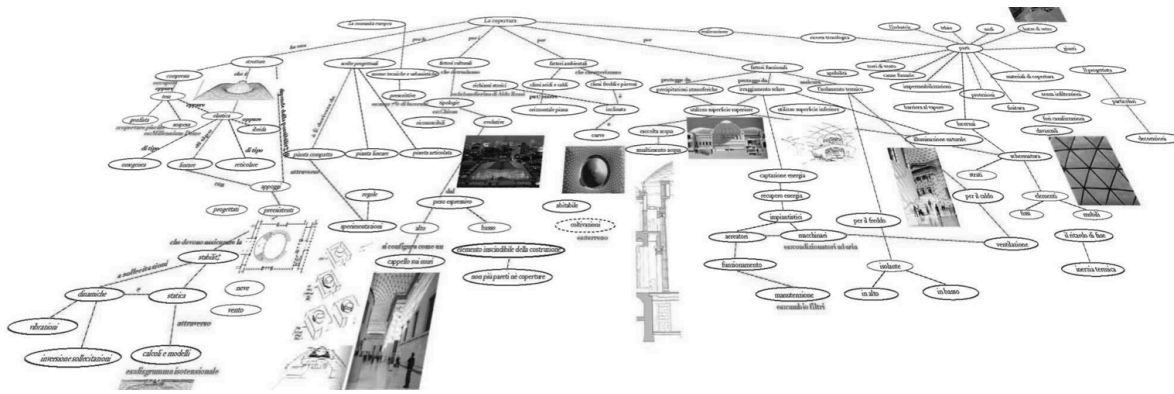


Figure 6: Map with concepts grouped into sets

Such a form of communication, or form of explanation, concentrates the key objects of the discourse in the concepts covered. However, by reporting the various concepts in a concept map, one runs the risk of having a confused form. To avoid this, the concepts have been grouped into sets.

2.6 Linking the description of the detail with the construction from which it was taken

Every good professional knows that, in addition to the reasons for the particularities of a detail presented, there are also reasons that allow one to arrive at a full analysis of the project. For this reason, it is interesting to describe the project in its entirety.

If the construction system is useful for understanding construction problems, the architecture system can be especially useful for helping people to understand the design choices made. Therefore, we determined it was equally essential to recall a brief description of the architectural design (Figure 7).

5.C L'ESEMPIO

Casa Hemeroscopium, Madrid, Spagna
Antón García-Abril

L'architettura di questa casa è un esempio emblematico dell'architetto che imposta la sua creatività essenzialmente sull'invenzione strutturale, concependo una struttura assolutamente gratuita e ingiustificata che, anche se crea spazi suggestivi, rimane fine a se stessa con pochi spunti per una utilizzazione futura.

La casa è realizzata costruendo un mastodontico quadrato strutturale sul quale è appoggiato un campionario di diverse travi prefabbricate da ponte.

La prima di queste è poggiata direttamente sul terreno; su di essa ortogonalmente è posta una trave a U rovescia con un appoggio a un estremo e l'altro posizionato verso i due terzi, in modo da lasciare una parte della trave a sbalzo. Su questo sbalzo si poggia la successiva trave a doppio T (1), sempre ortogonalmente, con un appoggio su un piccolo setto. Una trave Vierendeel, alla quanto la trave a doppio T (1), è ad essa incastata e poggiata sulla prima I. In questo modo si chiude il quadrato strutturale. Una trave a U è inserita nel quadrato poggiata su un vistoso cavalletto. Questa trave taglia lo spazio e permette di creare all'interno del quadrato un'ulteriore I. di travi spettacolarmente equilibrate da un enorme peso (blocco di granito di 15 tonnellate). La parte abitabile è ricavata chiudendo in maniera approssimativa gli spazi in questo intreccio strutturale.

Il particolare disegnato presenta la sezione di questa chiusura finalizzata, non al controllo della qualità ambientale, ma alla chiara lettura della struttura.

La progettazione si vanta di essere durata un anno con un montaggio di solo sette giorni come illustrato nel video di presentazione pubblicato in rete!

In sostanza, l'insegnamento che si può trarre da questa architettura è che interessarsi solo alla struttura è tanto dannoso quanto lo è disinteressarsene completamente.

5.D IL PARTICOLARE

- 1 Manto di copertura (S172-4) per realizzare una copertura piana: SC18 BENEVI con lastre prefabbricate di cemento su guaina impermeabile (LAV6 MAT13) (LAV6 MAT13)
- 2 Solaio di copertura (S111-3; S112-4) per coprire il primo livello (SC17) in pannelli prefabbricati alveolari (LAV6 MAT13)
- 3 Concreto gettato (S14-2) per coprire il fianco della copertura (SC18) realizzato con profili sagomati in lamiera zincata (LAV7 MAT14)
- 4 Trave parete (S111-2) per realizzare lo spazio del primo livello (SC17) prefabbricata da ponte h=2,30 m (LAV6 MAT13)
- 5 Pavimentazione (S172-2) per finire la pavimentazione del primo piano (SC17) (SC17) con un getto di letto e malta e finitura in cemento antiscivolo (LAV4 MAT13)
- 6 Solaio (S111-2) per realizzare il primo piano (SC17) prefabbricato alveolare (LAV6 MAT13)
- 7 Marciano sottoportante (S172-1) per coprire il fianco della struttura del primo piano (SC18) realizzato con un doppio profilo a C da 260 mm (LAV7 MAT14)
- 8 Controsoffitto (S132-2) per finire l'interno del primo piano (LAV11) con doppia lastra in cartongesso (LAV14 MAT12)
- 9 Vetusta (S172-1) per illuminare il primo piano (SC18 BENEVI) con soffitto metallico e vetrocamera tipo Climax 812/4x4 (LAV11 MAT13)
- 10 Pavimentazione (S172-2) per finire il pavimento (LAV11) (SC17) realizzato con un getto di cemento con ancore (LAV4 MAT13)
- 11 Solaio (S111-2) per realizzare il piano di appoggio del pavimento (SC17) realizzato con lastre prefabbricate in c.a. (LAV6 MAT13) (LAV6 MAT13)
- 12 Controsoffitto (S132-2) per sostenere la soletta del pavimento (SC17) (SC18) in c.a. gettato in opera (LAV14 MAT12)

BIBLIOGRAFIA E FONTI DELLE IMMAGINI:
- Mullers, E. (2009) Il paradosso della gravità. Casabella, 776, 24-31.

Figure 7: Description example

We believe this is the moment when one can address the essential reasons that led to the design of that particular element. In essence, through the design one can explain the detail.

2.7 Linking the detail in the construction with other similar details

As the detail is born of a designer's choice from among the many that he/she could have made, reference to such alternatives delves into the issue of the element in the study of the detail. To do this, the caption of the individual items of the elements studied is organized according to the system of unified classifications adopted. The link to the classifications allow one to conceptualize the problems and construct a clarifying rationale about them. At the same time, given that this conceptualization is closely linked to a well-defined example, one does not run the risk of making a crippling theoretical discourse.

2.8 Achieving a close connection between the elements of the construction system

In constructing discourses on different themes, sets appear that are part of several theme domains. For example, the concepts defined in the discourse on the 'structure' may also be present in the study of other elements (e.g. envelope or roofing). The concepts that recur in several elements thus constitute such links. Indeed, it is then possible to construct a multi-dimensional concept map defined by identical sets belonging to multiple themes, because a set that is a circle in a two-dimensional representation, it is a sphere in a three-dimensional one (Figure 8).



Figure 8: The set is a circle in a 2-dimensional representation, a sphere in a 3-dimensional one

This graphical representation, which is possible with new computer equipment, is impossible on paper. Also, the representation of the concept map, very clear with the new computer equipment, looks very complicated in paper form.

2.9 Connecting with traditional architectural journalism

The writings that are produced following this systematization of information are, for obvious reasons, greatly reduced. The information on choices of technologies is rather concise and one feels, therefore, the need to return to traditional forms of communication.

It was decided, therefore, to give each identified concept a reference bibliography where the reader can find a description of the same concept in a more extensive form.

This communicative aspect is in no way secondary to the discourse made; rather it is a key element in any in-depth analysis because, as Diderot remarked, the bibliography allows a panoramic vision of the concept discussed.

3. Application of the method

It seemed possible to concentrate the whole discourse on the building as a system in five papers published in as many booklets. It is evident that it would have been easier to make a more detailed breakdown of the themes discussed; however, wanting to show that it was possible to concentrate technological knowledge to the maximum, we employed a reduced breakdown.

The five themes identified are: ground anchoring, structure, envelope, roofing and floor plans, systems and secondary internal elements.

3.1 How content in publications are presented

The discourse on construction elements thus identified occurs through examples chosen to represent the various forms with which the elements themselves are materialized in architecture.

All the booklets contain a number of examples, i.e. constructions presented according to the form described. The concepts identified in the discussion of the example constitute the core of the general discourse presented in the concept map. Each example is shown in four pages in which one finds all the contents and information as described above (Figure 9).

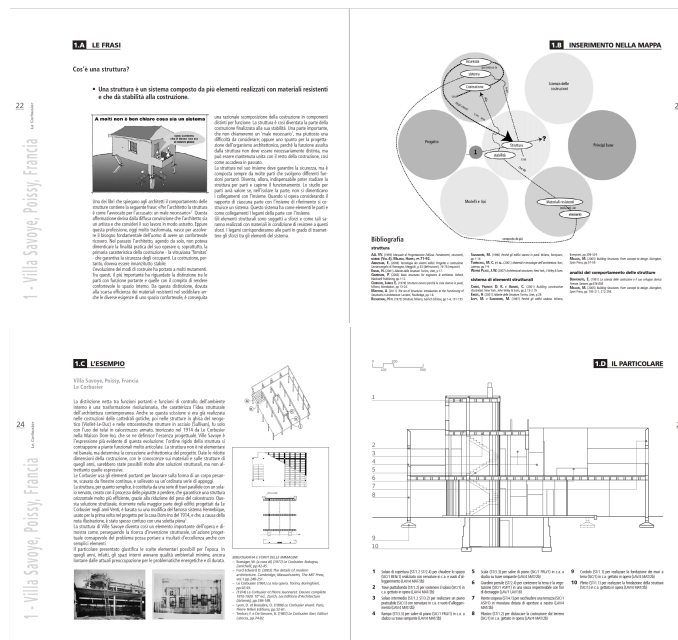


Figure 9: Contents of the four pages and reports

In this representation, the essence of our work is concentrated in an innovative form. With this graph we wanted to highlight the series of connections that exist between the information which, being presented in the traditional form, do not generally highlight the references that are indispensable for communicating the technological knowledge in a comprehensive way so that the system-construction engages with the system-architecture.

4. The construction as a set of forms materializing in the architecture

Underlying this discourse are examples that exemplify the choices used to represent the various forms in which the construction elements in the architecture materialize. Even if one adopts the concept maps, one should not lose sight of the fact that the information is not aimed only at knowledge, but rather is also a handy tool for an applied use. Basically, what we have proposed is essentially a refinement of the design procedures based on reasoning on the cases (CBR- Case Based Reasoning).

5. Discussion

Having wanted to maintain a very tight link between the proposed method and information commonly used by designers leads to our main intention which is a complete revolution of the communicative form. One can note that despite the current massive introduction of computer graphics, the journalistic style used by designers has not changed: what is usually presented is simply an adaptation or a reduction of the computer processing according to the traditional forms of the drawings, perspectives and false photographs, leaving everything unchanged.

What we are proposing, even if we consider only the organization of the captions of the drawings, is definitely a step towards more accurate communication. In publications today, one can see, in the captions of drawings, of the same element one is presented as “*flashing*”, another as “*completion of waterproofing*” and yet another as “*aluminum profiles*”. It would have been clearer, however, to write a caption organized thusly: “*Flashing (what) for completing the waterproofing (why) using an aluminum profile (how)*”.

Bringing order and communication, keeping the building as a system in mind, also involves communication such as we propose.

6. Conclusion

The publications are small-format (15x21 cm) of about 150 pages printed in black and white. The small size depends on the choice of matching the number of sentences contained in the map to the number of examples presented. Increasing the number of examples would surely enrich the volume, but processing them would lead to the need to increase the phrases needed for describing the element well. Therefore, this would make the conceptual map unwieldy, which, already with the limited number of concepts, would make it difficult to deal with the graphics problem. Only a complete computerization of the text could improve this rigid schema.

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Beyond the Built Environment as a Sustainable System: a New Approach to Modelling

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Abstract

This paper deals with the evaluation of sustainability as a theoretical, methodological and operational tool to support and improve learning on regenerative transformations of the built environment. In contrast with the scale-centred approach underlying the existing sustainability evaluation systems of buildings and urban areas, we propose i-UrBE (integrated-Urban Building Evaluation) an evaluation approach which draws on a socio-ecological interpretation of the built environment and is finalised to support a regenerative urban and building design. In our approach, the evaluation of the sustainability of a building or an urban plan is focused on *reciprocity* of interactions between human and non-human world, is carried out in a socio-ecological space that we define *urban matrix* and is based on few holistic indicators. These last are conceived as crucial tools reporting about what we define the *reliability* of an action, i.e. the ability of an action addressed to sustainability of buildings or an urban context to stimulate and transform into capacity the regenerative socio-ecological potential of a specific place.

Moving our work from the theoretical to the operational level, in this paper, we describe the evolution of i-UrBE approach for evaluating/assessing the regenerative sustainability of built environment focusing on *reciprocity* and *reliability* as crucial keys for an integrated urban-building evaluation. The paper underlines the relevance of *reliability* assessment based on few holistic indicators. In our evaluation approach, *reliability* reports on *reciprocity* by highlighting the ‘co-creative’ qualities of a design action addressed to a building to stimulate regenerative socio-ecological relationships shaping the built environment. At the operational level, *reciprocity* and *reliability* help to: (i) deal with sustainability in a pragmatic way on qualities inherent in an integrated process of urban-building design; (ii) improve knowledge generation on sustainability by enabling actors to identify trends, navigate sustainable transformations and highlight uncertainties associated with their actions.

Keywords: Regenerative Sustainability, Integrated Evaluation, Built Environment, Holistic Indicators.

¹ The paper is the result of a collective work. Attributions are as in the following: section 2, subsection 2.1, and section 3 are by Valeria Monno; section 1 and subsection 2.1.1 are by Emilia Conte; the abstract, subsection 2.2 and section 4 are by Valeria Monno and Emilia Conte.

1. Introduction

Evaluation systems in building and urban development have increasingly become a common language on sustainability among actors involved in making cities and urban areas smart, a fundamental tool to orient design and planning choices and influence the market. However, the large investments in this field have not produced the expected results, leaving significant margin for such systems development (Heinonen et al., 2015). One of the reasons determining scarce results is considered the lack of integration among different scales of evaluation of sustainability and in particular between the urban and building level. For example, considering urban sustainability as achievable through the evaluation of building sustainability has now become a new cliché, a sort of a ‘necessary’ activity to deal with climate change, energy savings or gas emission reduction in a smart way. Although necessary, this kind of building sustainability is not sufficient to speak about urban sustainability and improve it.

According to such a diagnosis, several solutions have been proposed in order to relate the urban and building sustainability better. These include the search for an intermediate scale of evaluation or multi-scalar evaluation frameworks. If, on the one hand, these solutions have not yet produced meaningful results, on the other they have generated an obsessive search for and proliferation of indicators and assessment systems that currently depicts a jeopardizing scenario (Reith and Orova, 2015) which risks to threaten the quality of results. From our point of view, in order to imagine and implement sustainable urban development a new approach is necessary.

2. i-UrBE: a socio-ecological interpretation of urban complexity

i-UrBE is a research project aimed at constructing a possible approach to tackle the urgent need for a cross-scale methodological framework for designing sustainability in the city by overcoming the limits shown by existing evaluation approaches linked to a scale-centred perspective, a linear conception of time and an archaic vision of integration among the socio-economic and environmental dimensions of sustainability. In contrast to dominant managerial approach to design and implement sustainability in the city, which sees evaluation procedures as an important tool to account for the results (Cole et al. 2013) and improve investment quality, in our research evaluation is conceived as an active learning process helping the design process. i-UrBE does not respond to a need for more complex and sophisticated evaluation technologies and tools. It offers a method and a tool enabling learning on what means and implies designing and planning sustainability in a spatially sensitive perspective. Despite the learning perspective could reduce the operability, efficacy and efficiency of i-UrBE, its use is a way to admit that when we deal with the evaluation of sustainability from an integrated, spatially sensitive perspective there is the constant need for doubt and dialogue (van der Knapp 2004).

In order to transcend the scale-centred perspective, our approach to the sustainability evaluation hinges on socio-ecological system (SES) interpretations of the built environment (Moffat and Kohler, 2008; Gandy, 2006). These are seen as indispensable to dismantle the anthropocentric vision on interactions between natural and urbanised worlds and a conception of urban

complexity as resulting from interactions among clearly bounded and isolated physical systems that, from our point of view, is at the base of the scale-centred approach.

According to SES, urban complexity can neither be reduced to the opposition between urban and natural worlds (Moffat and Kholer, 2008) nor disaggregated in a set of isolated social and ecological systems reciprocally interacting in some obscure way. Built environment is something more than the sum of the built (physical, economic, cultural and social) parts of cities and ecosystems from which it depends on (Hassler and Kholer, 2014). It reflects the socio-ecological relationships created by political decisions and the culture of design through which we interconnect in a specific way technical, environmental, economic, socio-cultural and political dimensions shaping urban life. If reconsidered from this point of view, nature is anything but a product of urbanisation and its metabolism (Kaika and Swyngedouw, 2014).

Anchoring this SES perspective to interpretations of urban complexity as assemblage (Latour, 2005; Gandy, 2008), the built environment can no longer be taken as a dead background for human and non-human life (Kaika and Swyngedouw, 2014). It evolves from complex and networked relationships among human and non-human agents (Monno and Conte, 2014). Any agent composing the built environment is a socio-ecological system in itself: it is a bridge between natural and human worlds which is shaped by and shapes the built environment. Each building, neighbourhood or infrastructure is individually a socio-ecological agent/node in the built environment. Therefore, the idea of the built environment as a socio-ecological networked assemblage includes a vision of urban space as emerging from the bottom-up, through the dynamics producing it.

Consequently, i-UrBE abandons a widespread idea of the built environment as an indefinite whole to be disaggregated into a collection of man-made objects (human-non human systems) interacting individually in a more or less complex way with local ecological dynamics or wider ecosystem through impacts or flows of matter and energy. It considers the built environment as a spatial context of interactions (assemblage) among different socio-ecological agents (buildings, infrastructures, public spaces, ecological dynamics, decisions, people, etc.) connecting urbanised and natural worlds in a specific spatial configuration. Although determined by a specific vision of urban space (i.e. the anthropocentric one), any agent can change the spatial context.

However, none of the agents can be considered in isolation from the spatial context in which it interacts. The set of networked socio-ecological relationships configures the spatial complexity and the sustainability of both the built environment and any individual agent/node composing it. This set of socio-ecological relationships determines the built environment metabolism, its influence on agents, as well as its spatial extension, and the level of quality of life (human and non-human) of the assemblage of agents.

Coherently to SES perspective on the built environment, i-UrBE evaluation approach also abandons the generic definition of sustainability intended as a process of integration of the economic, environmental and social dimensions of implementation to focus on the

transformations of the built environment in terms of regenerative behaviour (Monno and Conte, 2014). Rather than merely reducing, and then assessing, environmental social and economic impacts, and/or evaluating sustainable design choices comparing their performances to agreed sustainable targets, i-UrBE aims at supporting design choices triggering the transformation of the regenerative potential of the built environment into capacities (Mang and Reed 2012). As underlined by du Plessis (2012), “the regenerative paradigm provides an alternative that is explicitly designed to engage with a living world through its emphasis on a co-creative partnership with nature based on strategies of adaptation, resilience and regeneration” (p9).

In i-UrBE carrying out an integrated evaluation does not mean to discover a new scale for evaluating sustainability (as for example a neighbourhood), but understanding how to change the specific set of socio-ecological networked relationships shaping unsustainable metabolism and therefore working on those crucial relationships of *reciprocity* and interdependence linking agents composing the built environment so to make it regenerative.

2.1 From theory to practice

i-UrBE is thought of as the result of an evolutionary exploration method. This last facilitates new discoveries and the growth of knowledge since it proceeds by trial and error-elimination and is based on the idea that “as much as the experimenting agents, humans no less than other organisms, base their tentative problem-solutions on already acquired knowledge, wherever their trials go beyond what is already known they ‘cannot go but blindly’” (Vanberg, 2014, p101). The trial and error-elimination method generates a continuous move from theories to practice. Therefore, the construction of i-UrBE proceeds cyclically: the evaluation approach is translated into an integrated urban-building assessment framework for the evaluation of sustainability of the built environment and, then, critically analysed also involving experts in the field of sustainability evaluation.

i-UrBE evaluation approach is still under construction. At the current stage, it is the result of just one trial and error elimination cycle assuming as a test-bed of our socio-ecological approach an assessment framework for the sustainability of buildings.

The first provisional structure of the integrated assessment was determined by the need to make explicit the multiple urban-building socio-ecological (sustainable and unsustainable) reciprocal interdependences. In order to achieve this goal, and following the SES perspective, the built environment in which a building is localised was redefined as *urban matrix*. Within this definition, the *urban* alludes both to the urbanised space and to the urbanisation of nature. Hence, the *urban matrix* is more than the neighbourhood in which a building is situated: it is a multi-scalar space defined by the metabolic interactions among agents/nodes composing the neighbourhood and the sustaining ecological dynamics. The borders of *urban matrix* are defined by its metabolism, meaning by that the assemblage of socio-ecological networked material and immaterial flows and relationships connecting the agents composing the built environment to ecological dynamics. Within the *urban matrix*, a building is an agent/node contributing to and

shaping the *urban matrix* metabolism. Therefore, it is through metabolism that the built environment and a building interact.

The integrated assessment framework was also determined by the need to make explicit the *urban matrix* metabolism by identifying the multiple *urban matrix*-building sustainable and unsustainable reciprocal interdependences. At this purpose, we identified as categories of analysis of the *urban matrix* metabolism its physical structure, flows of matter and energy, environmental quality, and lifestyles. The sustainable building was instead described through its performances, as used in the most popular assessment systems, but reorganised in the following macro-categories: site, indoor and outdoor environment, operation and technical design. The vulnerability of *urban matrix* was chosen as a parameter able to represent at what extent a design action addressed to a building can change the *urban matrix* metabolism and if such a change can be able to activate an *urban matrix* resilient behaviour (Conte and Monno, 2012).

2.1.1 A focus on the evaluation of sustainable buildings: the need for *reliability*

To allow the assessment of a sustainable building in a SES perspective on the built environment we introduced the *reliability* concept. *Reliability* is a concept largely used in several fields of study to connect the effectiveness of an action to an expected behaviour of a system. Usually, this concept represents the ability of an agent –human or not human– to behave in an expected way during time, and the likelihood of an action to be effective. For example, in engineering fields it is adopted in relation to maintenance operations (EN 13306:2010); in the construction field it refers to a maintenance action capable of triggering an integrated and cooperative functioning among different components interacting in a building system. We retained the engineering definition of *reliability* of a system as being able to perform cooperatively. However, working in a socio-ecological system and a regenerative perspective, we dismissed its deterministic features. We then defined the *reliability* of a building as the ability of a sustainable building, basing on its design choices, to activate a cooperative integrated system of interactions between the building itself and the built environment (Conte and Monno, 2012). Thus defined *reliability* is a connector among scales of evaluation and a crucial conceptual tool to carry out both theoretically and operatively an integrated approach to sustainable design. *Reliability* could be assessed through few holistic indicators thought of as a combination of indicators representing a specific macro-category of analysis obtained through a comparison between macro-categories describing the sustainability of both buildings and the *urban matrix*. Such indicators measured those performances of a building inducing a vulnerability change in its context, i.e. impacts of a sustainable building on the built environment.

2.2 A critical analysis of the assessment framework

Once built the i-UrBE assessment framework (Fig.1), we verified if it was able to relate the sustainability of a building to the multiple dimensions shaping *urban matrix* metabolism. Our analysis showed that it was able to focus on socio-ecological relationships rather than on social, economic and environmental characters of urban and building sustainability. By relating the sustainable building to the variations of vulnerability of the *urban matrix*, it also helped to

correlate better local and ecological scales of evaluation as well as natural and cultural worlds. Comparing i-UrBE integrated assessment framework to the existing assessment systems, it showed what is missing in them and how it could complement them helping to make the design more powerful and the evaluation more transparent.

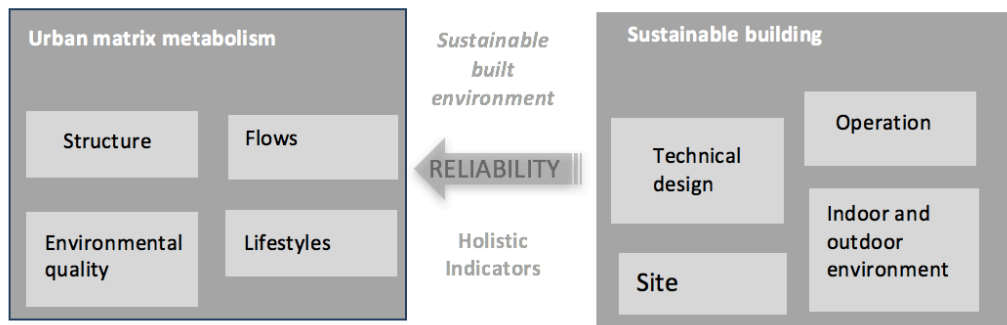


Figure 1: i-UrBE provisional assessment framework

Nevertheless, an inter-scalar perspective on the assessment was still recognisable, so weakening the integrative potentialities of i-UrBE evaluation approach. Furthermore, the regenerative perspective had not properly been incorporated in the assessment framework. Although expressing the *urban matrix*-building relationships, the variations of vulnerability showed a strong focus on resilience. The assessment of *reliability* was focused on the building and its impacts on the *urban matrix*, rather than on the interactions between the building and the *urban matrix*.

Parallel to this critical analysis, we discussed our approach to the integrated evaluation with some experts who actively work in the field of building and urban sustainability at the regional and national level. Experts were involved through semi-structured interviews and personal communications (face-to-face conversations). In depth, semi-structured interviews and face-to-face conversations were intended to grasp both technical and tacit knowledge as well as potential improvements and inadequacies of the existing evaluation systems of sustainable buildings and neighbourhoods when contextualised in an urban context. They also concerned issues related to inter-scalar urban-building relationships and the idea of urban complexity.

In both interviews and personal communications, we asked experts to give us their opinion about the efficacy of current evaluation systems in orientating design for sustainability and describe what causes the shortcoming of their action. They ascribed the modest efficacy of their action to contextual institutional, cultural and political constraints, rather than to the evaluation systems they had used for assessing urban or building sustainability. In particular, the experts emphasised the extremely usefulness of these systems in promoting sustainability of buildings. Yet, when obliged to reflect on the efficacy of these systems, experts could not avoid arguing that they should be considered as an initial step towards urban sustainability mainly aimed at changing the current unsustainable culture underlying the process of production of the city.

From experts' point of view, existing evaluation systems can help to measure the sustainability of a building intended as a producer of environmental pressures. However, they can only slightly challenge dominant economic driven conceptualisation of what is a sustainable building and what constitutes its contribution to the sustainability of the urban context in which it is situated. These systems are mainly used to favour the improvement of the (energy) efficiency of urban environments and buildings. Although buildings could reduce pollution, natural resources depletion and gas emissions in the atmosphere, the environmental urban quality still remains underestimated, social aspects undervalued and no meaningful regenerative clues of built environment could be detected. For the experts, one of the most important problems with the current evaluation systems is the absence of a multi-scalar perspective, which prevents them from linking sustainability of a building to urban sustainability and vice versa.

As far as the experts' opinion on our assessment framework is concerned, they found interesting both i-UrBE approach and the concept of *reliability*. They perceived the socio-ecological approach as a perspective capable of filling the absence of an integrated and inter-scalar evaluation and assessment. For them, i-UrBE approach pushes current mainstream ways of evaluating sustainable buildings towards a new way of conceiving the relationships between the building and the built environment. After we explained the meaning of *reliability*, experts started to think about the interactions among a sustainable building and the urban context.

For example, one of them argued that in order to consider a building sustainable, a new set of actions should be imagined beyond the existing approaches. These actions would imply reconstructing parts of a city to restore the relationships connecting buildings to the ecosystems, or transforming existing buildings so to regenerate the urban environments according to the ecological dynamics shaping the nature in the city. However, from their point of view, our approach and assessment framework could complement but not substituting the existing systems.

Interviews and face-to-face conversations confirmed the result of our critical analysis of the assessment framework. The *reliability* concept was too related to the performances of a building. Although being a useful conceptual tool to assess a potentially integrative building-urban reasoning, *reliability* only partially responded to the need for considering reciprocal interactions between buildings and the *urban matrix*. There was not a clear relationship between vulnerability and *reliability*. Hence, we were unfit to define and identify meaningful holistic indicators. Consequently, in the assessment process the use of *reliability* did not allow us to really understand if the interactions between a sustainable building and the *urban matrix* triggered an interdependent and regenerative process of the built environment.

By paraphrasing Costanza (2014), we had to admit that making the transition to the world we want is not easy since “in many ways we are locked-in, trapped, and in a very real sense “addicted” to the current regime” (p43). Both the concept of *reliability* and the holistic indicators had to be reframed.

3. *Reciprocity* as a regenerative quality of sustainable built environment

In order to make i-UrBE more adherent to the socio-ecological perspective as described above, we focused on *reciprocity* as crucial spatial quality of any sustainable built environment. *Reciprocity* implies the existence of co-constituting and mutually supportive spatial interactions among the agents composing a sustainable built environment seen as socio-ecological networked assemblage. Accordingly, we adopted a new definition of *reliability* that draws on the regenerative approach (Mang and Reed 2012), as it emphasises co-creativity among human and non-human worlds (du Plessis 2012). Co-creativity emphasised by the regenerative approach assures the interdependence which should characterise a socio-ecological sustainable built environment. Within this last, the co-creative performances do neither belong to a building nor to its ecological dynamics: they represent the potential and existing regenerative socio-ecological relationships which mobilisation requires the involvement of local communities seen as an active (and not impersonal) agent of sustainability.

Having in mind the idea of *reciprocity* as regenerative, co-creative quality of the built environment, in i-UrBE evaluation approach *reliability* is reconceptualised as the ability of a design action to trigger a system of interactions among different agents composing the built environment (for example buildings, ecological dynamics, local communities) so to exploit its regenerative potential and transform it into regenerative capacities. *Reliability* has to express the ability of a design action (a plan, a project, a technical solution) to activate a co-creative system of interactions between the building and the *urban matrix*. Furthermore, *reliability* can no longer be a feature of an agent defined by generic actors: it has to be reconceived as a result of a democratic, collective judgment involving ethical issues and concerning responsibility, accountability and transparency of decisions and decision-makers.

This new focus on *reciprocity* and the co-creative performances signals a crucial shift in i-UrBE assessment framework. The new assessment framework describes the features of *reciprocity*, i.e. the kind and direction of transition towards sustainability triggered by the design process in the built environment (Fig. 2). Besides considering *reliability* in terms of the impacts produced by a sustainable building on the different kinds of metabolism of an *urban matrix*, the assessment of *reliability* also focuses on the transformations of *urban matrix* metabolism into a regenerative one. In particular, in the new assessment framework, *reciprocity* helps to define the kind and the ‘degree’ of *reliability*, and, hence, it helps to understand and navigate the transformation activated by sustainable building design actions in the *urban matrix* showing its changes towards co-creative performances.

At the present stage of the research, we have identified four evaluation criteria expressing *reciprocity* and that can help to assess *reliability* through holistic indicators. The evaluation criteria are: cooperation, regeneration, adaptation and alignment. These criteria are crucial to signal the regenerative, co-creative character of transformations enacted in the built environment. If the regeneration of existing situations of crisis and cooperation between natural and human systems are a basic characteristic of a regenerative metabolism, adaptive capacity

between natural and technical systems has to be activated in order to deal with the uncertainty underlying any design activity and guarantee the resilience of built environment to stresses and disturbances (Mang and Reed, 2012; du Plessis, 2012). Last but not least, a process of alignment between economic development requirements and socio-ecological worlds of life has to be detectable. The evaluation criteria stress the relevance to adopt design choices beyond the dominant economic culture, technological constraints and contextual limiting imperatives.

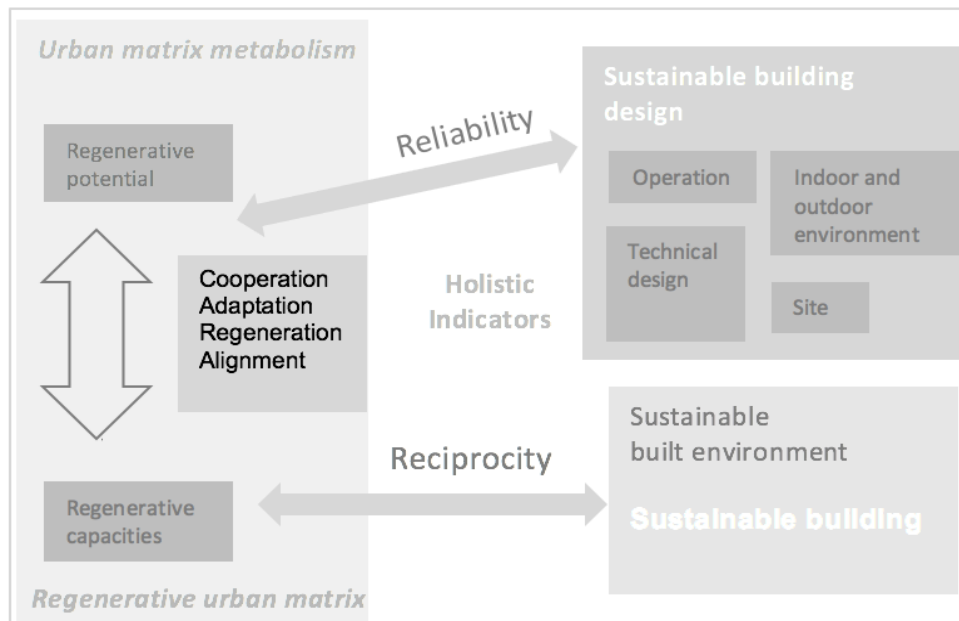


Figure 2: i-UrBE revised assessment framework

Operatively, the assessment framework enables to analyse how the regenerative potential of *urban matrix* shapes the sustainable building design and how, reciprocally, a sustainable building transforms that regenerative potential into capacities. However, due to the new definition of *reliability* in our assessment framework, the sustainability of a building can no longer be related to usual macro-categories describing its performances. They have to refer to the meta-design choices (a system of design actions) and their ability to trigger a regenerative process of a place. The vulnerability of the *urban matrix* remains an important parameter in the assessment. It still describes the variations of *urban matrix* resilience and metabolism and their regenerative direction. *Reliability* specifies the characteristic of that direction highlighting the kind of sustainability that is pursued through sustainable meta-design choices. The improvement of the assessment framework is showed by its ability to be applied to both urban and building design. In fact, for example, a sustainable urban plan has to produce reliable buildings.

Indirectly, *reciprocity* and the new definition of *reliability* highlight the transformative capacity, transversality, openness, and flexibility of the design process. The transformative capacity signals what and how much has been changed by the design process in the *urban matrix* metabolism. The transversality refers about the ability of a design action to interconnect socio-ecological relationships and shows the kind of interconnectedness (weak/strong). The openness highlights what has been ignored or lost in each of the four metabolic relationships and if there

is any possibility to change the project of a sustainable building or neighbourhood. The flexibility coincides with the possibility to adapt the project to changing situations.

4. Conclusions

This paper argues that the problem of spatial integration in the design and evaluation of sustainability of the built environment cannot be solved by working within the current existing approaches supporting and supported by evaluative and assessment frameworks. In fact, they have been flourishing within a vision of the world in which social and ecological systems are separated and observed through detached, scalar and hierarchical dimensions and structure of analysis. The paper then proposes i-UrBE, an integrated urban-building approach based on a SES reconceptualization of the built environment and the regenerative perspective on sustainability; it is an approach suitable for designing, evaluating and assessing sustainable built environments. In a socio-ecological perspective on the built environment, spatial integration is a challenge and an opportunity to radically restructure sustainability in the city and support its design through evaluation. Furthermore, considering that evaluation is more than an accounting activity, why not use it as a learning tool to promote the cultural shifts required by the regenerative sustainability perspective, proceeding in practice in parallel to the theoretical issues?

Following these premises, the paper discusses opportunities and challenges which have emerged throughout i-UrBE development. In particular, the paper stresses the theoretical and operative relevance of both a socio-ecological perspective on the built environment and the concepts of *reciprocity* and *reliability* of the action in structuring the spatially integrated evaluation process.

Reciprocity and *reliability* of an action in i-UrBE open up new development prospects for the integrated evaluation and assessment of sustainability of the built environment since they help to:

- report on the socio-ecological and regenerative performance of the process;
- consider actions in a co-evolutionary and integrated spatial perspective;
- contextualise the action without disconnecting it from proximate and distant spatial relations;
- focus on meta-design actions;
- measure the ability of an action to stimulate the co-creative and adaptive capacities of the context and the level of activation of its regenerative potential;
- actively involve a wide range of actors, many of those are only rarely considered in the design and evaluation process;
- show potentialities of actions directed towards a regenerative development process.

In particular *reliability* stimulates innovation of available knowledge and current technologies – particularly those fielded and used in recent decades as an attempt to move towards a sustainable development– and encourages experimentation (de Vries and Peterson, 2009). At this stage of the research, we refrain from identifying the holistic indicators to assess *reliability* and the methods to measure them. As we have shown, *reciprocity* and *reliability* assessment

cannot be the result of an expert activity which randomly involves communities with the aim to complement or complete certain phases of the assessment and in relation to certain requirements of the evaluation procedure. Design choices, evaluation criteria and holistic indicators for measuring *reliability* can only be defined through a collective effort involving expert and local knowledge. Their dialogic and democratic construction will not exclude conflicts so to highlight what has still to be done towards the construction of a socio-ecological co-creative built environment.

Although in an ongoing process of development, i-UrBE already proposes a different way of thinking, speaking about, designing and evaluating sustainability in the city that we suggest can efficiently contribute to sustainability implementations. By focusing on *reciprocity*, the co-creative performances in the *urban matrix*, and *reliability* of buildings, i-UrBE offers a possible operative way to overcome the limits of existing scale-based frameworks for designing and evaluating sustainability in the city, thus making our judgment on sustainability more consistent.

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Building Information Modelling: Point of Adoption

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Abstract

Building Information Modelling (BIM) is the current expression of construction industry innovation generating a wide range of augmented market deliverables, new requirements and emergent roles. For organizations to cross the innovation chasm, they need to progressively implement complementary tools, workflows and protocols. Such multifaceted implementation is not instantaneous but passes through recursive periods of implementation readiness, capability acquisition, and performance maturity. Similarly, BIM diffusion within organizations is not a frictionless derivative of BIM implementation, but a function of competition dynamics and institutional isomorphic pressures. While there are a number of academic studies and industry surveys covering organisational readiness, software implementation or innovation diffusion, there is no single conceptual construct to describe, explain and test BIM adoption as a single construct connecting all these concepts. Based on published research and experiential knowledge, this paper introduces the Point of Adoption (PoA) model which integrates these concepts into a single visual model. The PoA model – not only clarifies the connection between these concepts but – facilitates the assessment of current organisational abilities, and clarifies a step-wise approach to BIM adoption and continuous performance improvement.

Keywords: BIM Implementation, Performance Assessment, Innovation Diffusion

1. Introduction

Building Information Modelling (BIM) is an expansive knowledge domain. Over the past few years, much research has been conducted into the connotations and impact of BIM tools and workflows on the construction industry. BIM has been repeatedly described as a ‘disruptive technology’ (Smith & Tardif, 2009, p. 32) instigating a ‘process change’ (Eastman, Teicholz, Sacks, & Liston, 2011, p. vii), or as an ‘unbounded’ and ‘systemic’ innovation (Harty, 2005, p. 51) (Taylor & Levitt, 2004, p. 84). These and other descriptions invariably position BIM as the *current* expression of innovation within the industry, and that BIM technologies, processes and policies are significantly impacting industry’s deliverables, relationships and roles. While there are numerous studies relaying the many benefits of BIM, there are far fewer studies identifying the steps taken by organisations to realise these benefits. To remedy this shortfall, this article presents a performance model which overlays the concepts of BIM readiness, BIM implementation, and BIM diffusion.

2. Research Methodology

This section introduces the methodology used in developing the Point of Adoption model. The exercise builds upon and further extends the BIM Framework (Succar, 2009) by employing its existing conceptual constructs – terms, classifications, taxonomies, models and frameworks – to identify, explain and test new constructs. Through the ‘BIM Framework’s Conceptual Reactor’ (Figure 1), a theory-building exercise is conducted using three iterative stages (J. R. Meredith, Raturi, Amoako-Gyampah, & Kaplan, 1989) (J. Meredith, 1993). The first stage develops a *description* of reality; identifies phenomena; explores events; and documents findings and behaviours. The second *explanation* stage builds upon descriptions to infer a concept, a conceptual relationship or a construct; and then, develops a framework or a theory to explain and/or predict behaviours or events. Finally, the third *testing* stage inspects explanations and propositions for validity; tests concepts or their relationships for accuracy; and tests predictions against new observables. The proposed Point of Adoption model follows a cyclical path as the one described by J. Meredith (1993) from describing; to explaining; to testing; and then back to describing. First, the model is generated through process of inductive inference (Michalski, 1987), conceptual clustering (Michalski & Stepp, 1987) and reflective learning (Van der Heijden & Eden, 1998) (Walker, Bourne, & Shelley, 2008). Second, conceptual models are developed to visually *explain* the knowledge structures. Third, each model is *tested* through either a focus group, peer-review questionnaire, or focus groups (Succar & Kassem, 2015).

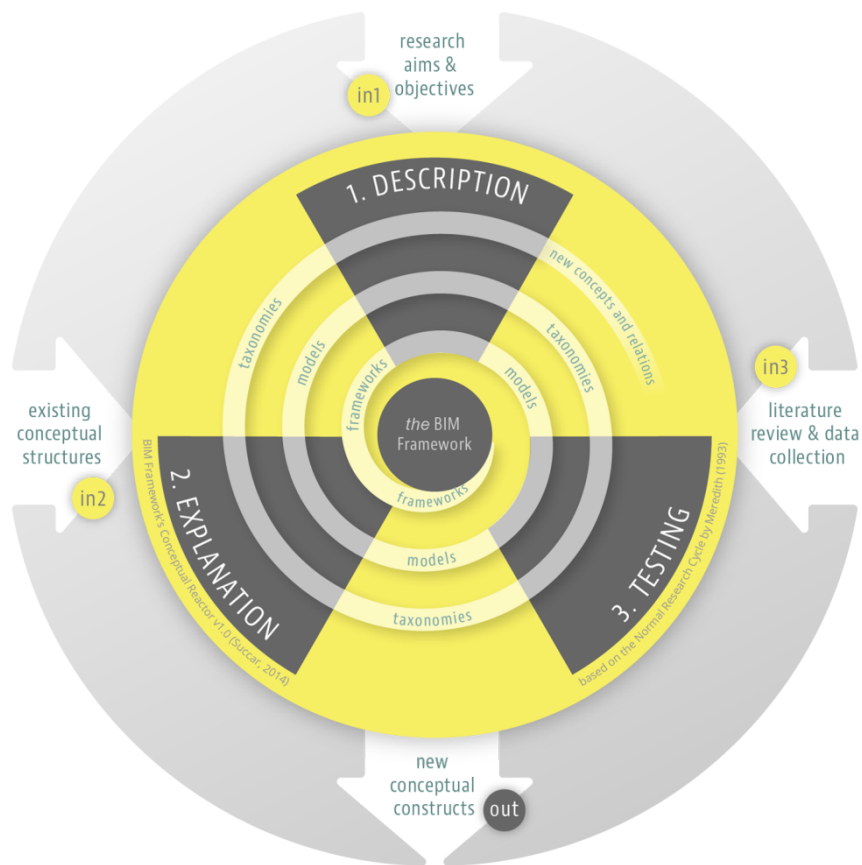


Figure 1. The BIM framework conceptual reactor

3. Terms, Concepts and their interaction

Before introducing the Point of Adoption (PoA) model, it is prudent to delimit a number of terms. The terms used to describe the act of implementing an innovative system/process are often confused with the terms used to describe the spread of this system/process within a *population* of adopters – be it within an organization or across a market. This delimitation is both artificial and necessary: it is *artificial* as other researchers can recalibrate the connotations of the same terms to fit their own unique purposes. It is *necessary* due to the availability of a large number of relevant diffusion models (Pierce & Delbecq, 1977) (Saga & Zmud, 1993) (Fadel, 2012) which do not differentiate between the stages of implementation - e.g. between acceptance and routinization as in Cooper and Zmud (1990) - the mechanics of diffusion, and the pressures causing the shift from one stage to another.

In introducing and delimiting these terms, we also limit ourselves to BIM as an innovative set of tools, processes and policies within the construction industry. This limitation is also both artificial and necessary: it is *artificial* as implementation/diffusion models introduced later are arguably applicable to other innovations within and outside the construction industry (e.g. to GIS and PLM). It is *necessary* due to the dearth of investigations covering innovation diffusion

within the construction industry (Taylor & Levitt, 2004) thus warranting – as exemplified below - a focused attention on industry-specific and, by extension, BIM-specific terms.

3.1 BIM Implementation

Implementation refers to the wilful activities of an identifiable player¹ as it adopts a novel system/process to improve its current performance. More specifically, *BIM implementation* refers to the set of activities undertaken by an *organizational unit* to prepare for, deploy or improve its BIM deliverables (products) and their related workflows (processes). BIM implementation is introduced here as a three-phased approach separating an organization's *readiness* to adopt; *capability* to perform; and its performance *maturity*:

- BIM readiness is the *pre-implementation status* representing the propensity of an organization or organisational unit to adopt BIM tools, workflows and protocols. Readiness is expressed² as the *level of preparation*, the *potential to participate*, or the *capacity to innovate*. Readiness can be measured using a variety of approaches – product-based, process-based, and overall maturity (Saleh & Alshawi, 2005) – and signifies the planning and preparation activities preceding implementation;
- BIM capability is the wilful *implementation* of BIM tools, workflows and protocols. BIM capability is achieved through well-defined *revolutionary stages* (object-based modelling, model-based collaboration, and network-based integration) separated by numerous *evolutionary steps* (Succar, 2009). BIM capability covers many technology, process and policy topics and is expressed as the *minimum ability* of an organization or team to deliver a measureable outcome; and
- BIM maturity (or *post-implementation*) is the *gradual and continual improvement* in quality, repeatability and predictability within available capabilities. BIM maturity is expressed as *maturity levels* (or performance improvement milestones) that organizations, teams and whole markets aspire to. There are five maturity levels: [a] Ad-hoc or *low maturity*; [b] Defined or *medium-low maturity*; [c] Managed or *medium maturity*; [d] Integrated or *medium-high maturity*; and [e] Optimised or *high maturity* (Succar, 2010).

3.2 BIM Diffusion

In contrast to *implementation* which represents the successful adoption of a system/process by an organization, diffusion represents the spread of the system/process across the organization. That is, the diffusion of a solution occurs after the solution has been adopted (Peansupap & Walker, 2005) or what we term as the *Point of Adoption* (PoA). However, the mere acquisition of an innovative solution (e.g. a software) “need not be followed by widespread deployment and use by acquiring organizations” (Fichman & Kemerer, 1999, p. 256).

¹ Depending on the ‘scoping lens’ applied, BIM players are either individuals, groups, organizational units, or whole organizations. BIM players, deliverables and their requirements have been extensively covered in earlier works (Succar, 2009).

² Definitions adopted from the e-commerce context as used by the Asia-Pacific Economic Cooperation (APEC), Center for International Development (CID) at Harvard University (CID, 2014).

E. M. Rogers (1995, p. 5) defines diffusion as the “process by which an innovation is communicated through certain channels over time among the members of a social system”, a definition that covers the increase in “number of firms using or owning a technology (inter-firm diffusion) [and the] more intensive use of the technology by the firm (intra firm diffusion)³” (Stoneman & Diederer, 1994, p. 919) (Mansfield, 1963). Diffusion is also identified as the third and final phase of the well-noted Schumpeterian Trilogy: “invention (the generation of new ideas), innovation (the development of those ideas through to the first marketing or use of a technology) and diffusion (the spread of new technology across its potential market)” (Stoneman & Diederer, 1994, p. 918).

There are numerous studies dedicated to innovation diffusion across a population of adopters (Bass, 2004; Kale & Ardit, 2010; Mansfield, Rapoport, Romeo, Wagner, & Beardsley, 1977; E. M. Rogers, 1995). These studies either explain and expand-upon the S-curve diffusion pattern (Cumulative Normal Distribution) (Everett M Rogers, Medina, Rivera, & Wiley, 2005) consistently encountered when analysing the spread of innovation; or introduce *diffusion models* that “depict the successive increases in the number of adopters and predict the continued development of a diffusion process already in progress” (Mahajan, Muller, & Bass, 1990, p. 2).

According to Geroski (2000), there are two main types of diffusion models providing insights into the manner and speed of technology adoption – the epidemic model and the probit model. The ‘epidemic’ diffusion model attributes the diffusion of technology (software in particular) to a given population’s knowledge of its existence; its comparative benefits; and the spread of its use through word of mouth. As a result, in the epidemic model the spread of innovation is largely affected by the transfer of knowledge and information among the involved population. As it focuses on a whole population of adopters, the epidemic model is interested in the gradual, unfolding impact of a new system/process on a market through its aggregate use. This contrasts with the ‘probit’ and ‘salience’ diffusion models which focus on the effect of *individual decision-making* on the spread of innovation and account for the differences in adoption time between individuals due to their distinct goals, needs and abilities (Geroski, 2000, p. 614; Strang, 1991).

This individual decision-making affecting diffusion follows three identifiable patterns – contagion, social threshold and social learning (Young, 2006, p. 4):

- Contagion represents how an industry player (e.g. an engineer or an engineering company) adopts an innovative system/process upon *contact with another player* who has already adopted it;
- Social Threshold represents how an industry player adopts an innovative system/process when *enough similar players* have adopted it; and
- Social Learning represents how an industry player adopts an innovative system/process when *enough proof is available* of prior adopters finding it worth adopting.

³ To avoid conceptual overlap, the spread of a solution within an organizational unit will not be referred to as intra-diffusion but as improved implementation (or higher level of maturity) across the whole organization.

These diffusion models and patterns have been shown to collectively describe and help predict the incremental diffusion of technological solutions across a population. However BIM is not solely an innovative technological solution proliferating incrementally across the construction industry (Fox & Hietanen, 2007) (Mutai, 2009) (Gu & London, 2010) but a an organizational and *systemic* innovation (Taylor & Levitt, 2004) of complementary technologies, processes and policies. While BIM may be initially classified as a *technical innovation* (Murphy & Wardleworth, 2014), it will need to be urgently reclassified - upon its transformative adoption by organizations - as an *organizational innovation* characterised by the “generation, acceptance, and implementation of new ideas, processes, products or services” (OECD, 2005; Thompson, 1965, p. 2).

As covered in depth in earlier research (Succar, Sher, & Williams, 2012) and briefly explored in Figure 1, BIM adoption by an organization passes through three adoption points pertaining to three capability stages. Even if multiple organizations pass through the first Point of Adoption (PoA) separating pre-BIM status from minimum BIM capability (Stage 1), the spread of *modelling* practices among this population does not necessarily or automatically translate into a diffusion of multidisciplinary *collaboration* or interdisciplinary *integration* practices (Stages 2 and 3 respectively). Similarly, BIM is not a mere technological solution but reflects a combinatory and mutational diffusion of technologies, workflows and protocols (Merschbrock & Munkvold, 2014) (Yoo, Richard J. Boland, Lyytinen, & Majchrzak, 2012). This multi-stage, multi-faceted, and multi-component nature of BIM – resembling a *complex adaptive system* (Johnson, 2002) - prevents the effortless application of technology-centric diffusion modelling and invites the development of more representative BIM adoption models.

4. Point of Adoption Model

The Point of Adoption (PoA) model combines many of the concepts introduced earlier (Figure 2). In addition to distinguishing between invention, innovation and diffusion (Stoneman & Diederer, 1994), the three implementation phases – readiness, capability, and maturity - are also depicted). As explained further below, PoA is a term that identifies the juncture(s) where organizational readiness transforms into organizational capability:

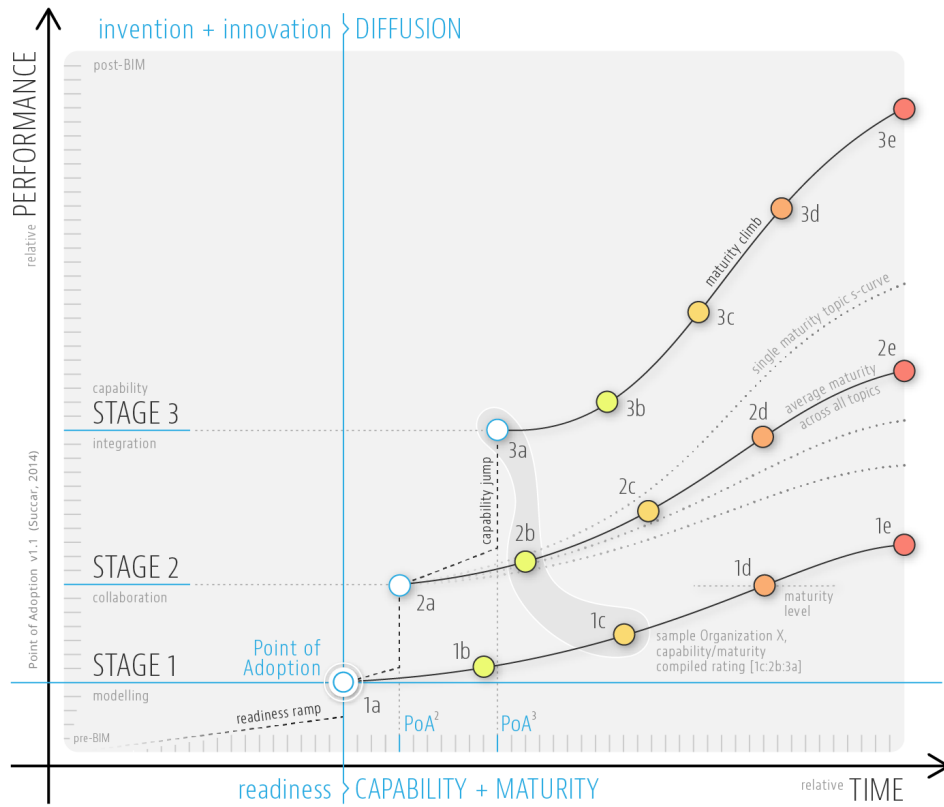
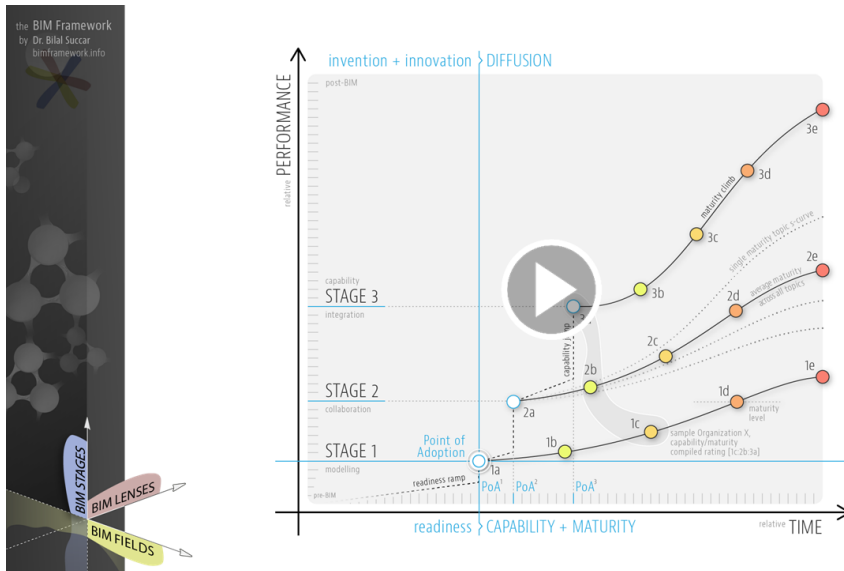


Figure 2. Point of Adoption model v1.1 (full size, current version)



Video 1 . Point of Adoption Video ([YouTube Link⁴](#))

⁴ Point of Adoption (PoA) video on YouTube: https://www.youtube.com/watch?v=weMqv31Np_4 (16:33)

As explored in Figure 2 and clarified in Video 1, transformative BIM adoption starts at the Point of Adoption (PoA) when an organization, after a period of planning and preparation (readiness), successfully adopts *object-based modelling* tools and workflows. The PoA⁵ thus marks the initial *capability jump* from no BIM abilities (pre-BIM status) to minimum BIM capability (Stage 1). As the adopter interacts with other adopters, a second capability jump (Stage 2) marks the organization's ability to successfully engage in model-based collaboration. Also, as the organisation starts to engage with multiple stakeholders across the supply chain, a third capability jump (Stage 3) is necessary to benefit from integrated, network-based tools, processes and protocols. Each of these capability jumps is preceded with considerable investment in human and physical resources, and each stage signals new organizational abilities and deliverables not available before the jump. However, the deliverables of different organizations at the same stage may vary in quality, repeatability and predictability. This variance in performance excellence occurs as organizations climb their respective BIM *maturity curve*, experience their internal BIM diffusion, and gradually improve their performance over time⁶.

The multiple maturity curves depicted in Figure 2 reflect the heterogeneous nature of BIM adoption even within the same organization (e.g. sample Organization X in Figure 2 has a compiled rating of 1c, 2b and 3a). This is due to the phased nature of BIM with each revolutionary stage requiring its own readiness ramp, capability jump, maturity climb, and point of adoption. This is also due to varied abilities across organizational sub-units and project teams: while organizational unit A1 (within organization A) may have elevated *model-based collaboration* capabilities, unit A2 may have basic modelling capabilities, and unit A3 may still be at the readiness stage preparing to implement BIM software tools. This variance in ability necessitates a compiled rating for organization A as it simultaneously prepares for an innovative solution, implements a system/process, and continually improves its performance.

5. Conclusions

The Point of Adoption (PoA) model represents the sequence and relationship between multiple performance assessment concepts. By overlaying the readiness, implementation, invention, innovation and diffusion concepts into a single term, and into a single visual representation, the PoA model clarifies the progression of BIM adoption within and across organisations. Also, through well-defined BIM Capability Stages and BIM Maturity Levels, the PoA model offers a simplified template for measuring BIM performance as well as for planning structured BIM adoption activities.

⁵ The Point of Adoption (PoA) is not to be confused with the critical mass 'inflection point' on the S-curve (E. M. Rogers, 1995) (Everett M Rogers et al., 2005); or with the 'tipping pint', the critical threshold introduced by Gladwell (2001).

⁶ The X-axis in Figure 2 represents time relative to each PoA, not as an absolute scale. That is, this version of the chart does not represent a snapshot view of compiled capability/maturity at a specific point in (absolute) time.

The PoA model has several theoretical and practical implications. At the theoretical level, it demonstrates how (a) BIM is a multifaceted innovation; (b) current theories of innovation diffusion may be inadequate for studying BIM diffusion; (c) it is possible to overlay the concepts of readiness, implementation and diffusion into a single adoption model; and (d) the need for a more in-depth theoretical study to underpin BIM adoption and multifaceted innovation diffusion.

At the practical level, the PoA model highlights (e) the simultaneous coexistence of varying BIM abilities within the same organisation; (f) the need to account for these variances when certifying organisations or pre-qualifying tender participants; and (g) the need to revise or discard the prevailing market maturity assessment methods which do not account for such variances.

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The Use of BIM in the Singapore Construction Industry: Opportunities and Challenges

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Abstract

The Singapore government has been actively promoting the use of Building Information Modelling (BIM) in the construction industry. Since 1 July 2015, all plans of new building projects with gross floor area (GFA) of 5,000 sq. m. and above have to be submitted in BIM format. Moreover, raising productivity in all sectors has been the top priority. On the safety part, the government has introduced a number of initiatives, with the main aim of reducing fatalities to 1.8 per 100,000 workers by 2018. Taking advantage of these initiatives, there are opportunities to maximise the potential of BIM to help improve productivity and safety in the industry. Semi-structured interviews were carried out from January to December 2014 to find out the industry's views on the current state of BIM, productivity and safety in the construction industry in Singapore. It was revealed that despite the support from the government and the opportunities offered by BIM, the industry faced a number of challenges in the implementation of BIM. They include collaboration, technical, legal issues, time and cost consideration. Many of the respondents acknowledged that BIM has a lot of potential, yet this had not been maximised. Much more needs to be done to further utilise BIM for improving productivity and safety in the industry. Hence, the paper highlights an intelligent system which has been designed to provide solutions for the challenges and create opportunities for the industry to derive greater benefits from BIM. The system incorporates both productivity and safety performance, using BIM as the platform.

Keywords: BIM, challenges, opportunities, productivity, safety

1. Introduction

1.1 Overview

The Singapore government has been actively promoting the use of Building Information Modelling (BIM) in the construction industry. It has identified BIM as a critical tool in the national productivity drive, which has the aim of raising the level of productivity in all sectors of the economy, including construction. Since 1 July 2015, all plans of new building projects with gross floor area (GFA) of 5,000 sq. m. and above have to be submitted for development approval in BIM format. On the safety part, the government has introduced a number of initiatives, with the main aim of reducing national fatalities to 1.8 per 100,000 workers by 2018. Singapore's Workplace Safety and Health Council (WSHC) outlined the national WSH 2018 vision, which is "A safe and healthy workplace for everyone and a country renowned for best practices in WSH" (WSHC, 2010). Taking advantage of these initiatives, there are opportunities to maximise the potential of BIM to help improve productivity and safety in the industry. However, the implementation of BIM by the firms is not without challenges. The paper outlines the opportunities offered by BIM and some of the challenges encountered by some of the firms in the construction industry of Singapore on their BIM journey. The paper also highlights an intelligent system which has been developed to address the challenges. The system was designed to provide solutions for the challenges and create opportunities for the industry to derive greater benefits from BIM.

1.2 Singapore's BIM Roadmap

Governments worldwide, including Denmark, Finland, Norway, South Korea, UK, and USA play an important role in leading the construction industry in BIM adoption. Singapore is one of a few countries in Asia which have implemented BIM (Wong *et al.*, 2009). Others are Hong Kong, PRC and South Korea. In Singapore, the Building and Construction Authority (BCA) implemented the BIM Roadmap in 2010 with the aim that 80 percent of the construction industry would use BIM by 2015. This is part of the government's plan to improve the construction industry's productivity by up to 25 percent over the next decade (BCA, 2011). The latest survey on BIM adoption (Lam, 2014) shows that almost all the firms in Panel One of the public-sector panel of consultants have adopted BIM (Figure 1). However, the adoption rate was not that high for contractors (Figure 2).

BCA introduced a number of initiatives to prepare the industry, following the BIM Roadmap (Figure 3). After the first BIM Roadmap was launched, a National BIM Steering Committee, comprising representatives of professional institutions, trade associations, major government procurement entities and regulatory agencies, was set up in 2011 to provide a governing framework to steer the implementation of the BIM Roadmap (BCA, 2013b). The committee led the development of the "Singapore BIM Guide" and "BIM Particular Conditions". Platforms such as BIM Manager Forums have been organised to discuss and address technical issues faced by the industry.

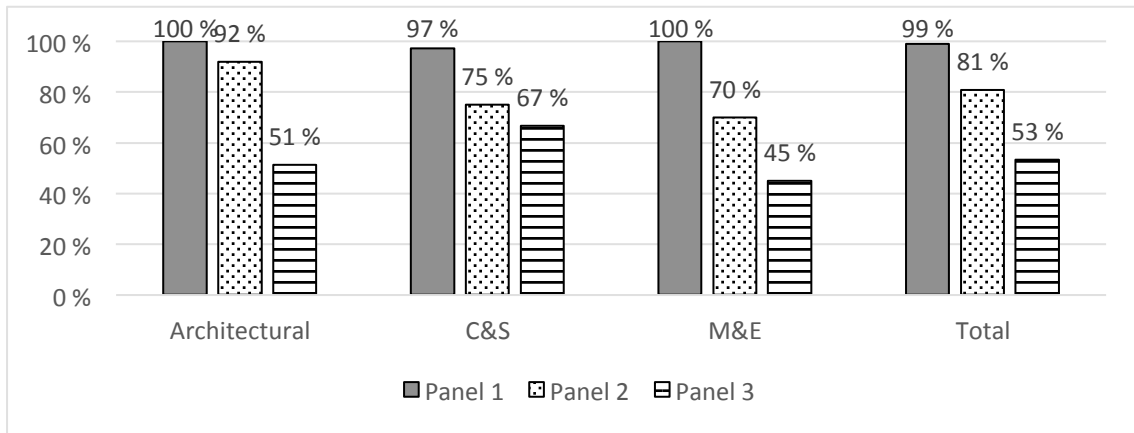


Figure 1. BIM adoption landscape of the public sector panel of consultants in the Singapore construction industry. Source: Lam (2014).

* Tendering limits:

Panel 1: S\$90 million

Panel 2: S\$42 million

Panel 3: S\$14 million

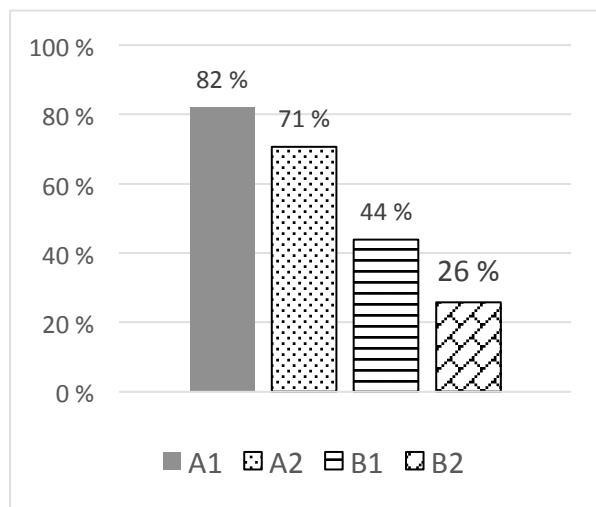


Figure 2. BIM adoption landscape of the Grade A1-B2 contractors. Source: Lam (2014).

* Tendering limits:

Grade A1: unlimited

Grade A2: S\$90 million

Grade B1: S\$42 million

Grade B2: S\$14 million

One of the initial challenges recognised in the BIM Roadmap is the need to obtain the manpower and financial resources needed to build up BIM expertise. To meet the high demand for skilled BIM manpower, BCA had been working closely with relevant Institutes of Higher Learning (IHLs), BCA Academy and BIM vendors to organise training and incorporate BIM in academic programmes. To overcome the challenge of obtaining the financial resources, the BCA BIM Fund provides incentives to construction firms to adopt BIM.

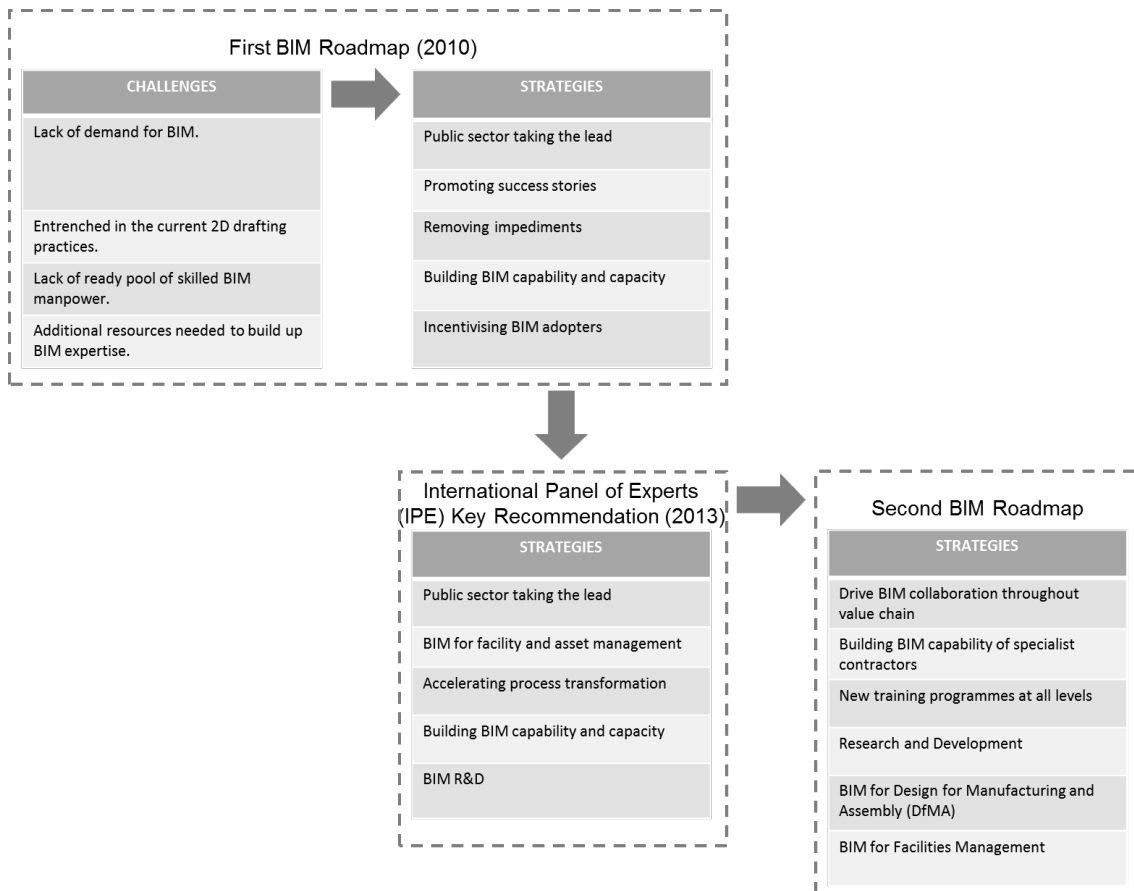


Figure 3: Singapore's BIM Roadmap. Source: Adapted from Lam (2014).

In 2014, the second BIM Roadmap was launched after the International Panel of Experts in BIM proposed a number of key recommendations, which included the public-sector taking the lead, BIM for facility and asset management, accelerating process transformation, building BIM capability and capacity and BIM R&D (Lam, 2014). The report presented a review of the current state of BIM adoption. The developers are detached from the BIM process and lack the know-how to drive the process. The consultants focus too much on e-submission and lack the time to undertake design co-ordination. Main contractors commented on the lack of quality models from consultants. The main contractors are currently not taking advantage of the full potential of BIM to resolve issues with consultants and subcontractors. The specialist subcontractors lack BIM skills. There is a lack of BIM usage for facilities management. It was also highlighted that there is a lack of BIM collaboration among project participants.

Hence, the main focus of the second BIM Roadmap is to drive BIM collaboration throughout the value chain. The funding level from the BCA BIM Fund had been increased from 50 percent to 70 percent for Project Collaboration Scheme. The "Singapore BIM Guide" and "Public Sector BIM Requirement" would be reviewed to include BIM coordination and model handover. Procurement methods and contract conditions would be developed based on BIM.

2. Literature Review: Opportunities and Challenges

The emphasis on national productivity and safety improvement, together with the drive for industry-wide BIM implementation, provides an opportunity for investigating how BIM could be used for improving productivity and safety in the construction industry.

BIM, as a process, allows the exchange of information among the project stakeholders, such as architects, engineers, contractors, consultants and clients. BIM is able to generate and analyse different views, data and information appropriate to various users' needs, which can be used to facilitate decision making and to improve the process of delivering the facility (AGC, 2010). The important feature of BIM is its capability to enable the item to be constructed to be built virtually, prior to building it physically, in order to identify and resolve problems, and simulate and analyze potential impacts (Smith, 2007). BIM can be used for many other purposes in the design and construction process such as visualization, scope clarification, trade coordination, collision detection and avoidance, design validation, construction sequencing planning, plans and logistics, marketing presentations, options analysis, walk-throughs and fly-throughs, virtual mock-ups and sight-line studies (AGC, 2010).

Teo (2014) discussed how BIM could be utilised help to improve productivity and safety in a number of ways. BIM could result in productivity improvement due to reduction in the disruption of the flow of information in the design and construction stages; effective response to changes during the construction stage; improved communication and collaboration among stakeholders in the construction project; informed decision-making; information sharing and interoperability; and fewer changes, less workload and more savings. The application of BIM in construction may improve the performance of onsite operations due to the reduction of manual efforts, time and costs involved (Gong and Caldas, 2011). During the construction phase, BIM contributes to the success of a project by enabling practitioners to effectively control schedule, budget and quality, and to reduce risks (Ku and Mills, 2008). Sacks and Barak (2006) report the reduction of total number of hours spent on three construction projects owing to the use of 3D modelling instead of 2D. Nath *et al.* (2015) found productivity improvements in the precast shop drawing generation due to the use of BIM.

Teo (2014) further argued that BIM could lead to safety improvement because BIM helps practitioners visualise the compatibility of architectural, structural and mechanical and electrical (M&E) design aspects, as well as feasibility of construction of design features or elements. BIM is able to simulate each step of work activities so that construction sequencing and the required safety measures may be identified. BIM also facilitates the communication of any identified safety risks to relevant stakeholders. Zhang *et al.* (2013) developed an automated safety checking platform which is able to inform construction engineers and managers of the various safety measures needed to prevent fall-related accidents before construction starts. The system automatically analyses a building model to detect safety hazards and suggest preventive measures to users. Benjaoran and Bhokha (2010) developed a rule-based system that is able to detect any work-at-height related hazards and propose necessary safety measures. Factors related to building components and activities such as component type, dimensions, placement,

working space, activity type, sequence, and materials and equipment are used as input data. These factors are examined to find any work-at-height hazards. Thereafter, the system is able to suggest necessary safety measures including activities or requirements. Choi *et al.* (2014) developed a BIM-based evacuation regulation checking system for high-rise and complex buildings. Their system allows architects, designers and owners to evaluate the design at the design stage to ensure that the design meets the design requirements. Continuous checks are possible due to an automated system and detailed guidelines.

Although BIM has the potential to improve overall construction project performance, it is also widely acknowledged that BIM brings about various challenges in its implementation. Among others, BIM requires collaboration among the project stakeholders. To implement BIM, owners and general contractors must select subcontractors with BIM experience. This changes the contractor selection process, which traditionally focuses on the lowest bidder. Meanwhile, BIM implementation requires a significant up-front investment. Furthermore, construction safety professionals often are involved late in the project development process, which does not allow them to contribute to BIM effectively. Technical challenges are also commonly encountered (Rajendran and Clarke, 2011). For example, adding construction safety elements and temporary systems such as scaffolding, boom lifts, cranes and scissor lifts into BIM can be a challenge.

3. Field Study

3.1 Interviews

The information for the part of the field study reported on this paper was obtained from a series of semi-structured interviews with representatives of twelve firms and institutions in the construction industry in Singapore. Semi-structured, face-to-face interviews were carried out from January to December 2014. The main objective of the interviews was to find out the views of the practitioners in Singapore's construction industry on the current state of BIM, productivity and safety in the industry.

There was a total of 30 interviewees from six contractors, two architectural firms, one cost consultancy firm; and representatives of a professional institution, a trade association, as well as representatives from the government. Selection of the interviewees involved a snowballing sampling technique. The first group of interviewees was identified from reports and articles indicating that they had played a key role in implementing BIM in their projects; or their companies had exceptional productivity and safety performance records.

3.2 Findings: Opportunities and Challenges

The interviews revealed that the firms were utilizing BIM at different levels. Some firms had been using BIM at relatively advanced levels. Some other firms still used BIM at the beginning stage, mainly for meeting the statutory requirements of building plan submissions in BIM

format. One firm was still testing the use of BIM internally, to prepare itself for full BIM implementation.

The interviewees acknowledged that BIM brings about many benefits. It helps to visualise, highlight the problems and propose solutions before construction starts. Project stakeholders could view, discuss and analyse different scenarios. BIM is also able to minimise communication and coordination problems among the different disciplines involved in a construction project.

The form of support from the government which had been most popular with the firms was the financial support provided. The majority of the firms of the interviewees had utilised the BIM Fund to the maximum limit. They acknowledged that the funding had been useful and expected that there will continue to be assistance from the BIM Fund in the future.

The interviews gathered that the firms faced a number of challenges in the implementation of BIM, three of the main ones of which are now highlighted. Firstly, BIM implementation requires a multi-disciplinary approach. Specifications in great details from consultants and contractors are required to develop a useful BIM model. For example, to integrate scaffolding specifications with design specifications, information from formwork or scaffolding suppliers is needed. However, many of the parties were concerned with the confidentiality of the information on their projects; hence, it sometimes took a longer time than necessary to share the required information.

Most of the time, an initiative from one of the project stakeholders is able to push the implementation of BIM. For example, one contractor took the initiative to develop an in-house BIM division and train its own personnel in BIM. The contractor developed the BIM models obtained from the consultants further. It also made sure the subcontractors (for the M&E works in this case) to update the BIM models so that the models could be coordinated with the architectural and structural models. It required a great deal of commitment as a significant amount of investment in terms of time, training and equipment is required. Some of the challenges include additional time commitment required for updating the models throughout the duration of the project. For example, subcontractors prefer 2D drawings to 3D and BIM models as they had more experience with the former than the latter. A significant amount of time was spent on modelling and checking as models submitted for submission often are not up to the standard required in the subsequent stages of the project. Hence, they still need to be further developed. In terms of human resources, it was always a challenge getting the people competent in BIM, since there was an acute shortage of these persons. The BIM team in the office needed more support from the site, hence the site team needed to be trained as well. The reluctance of the site personnel to provide this support was mostly due to lack of knowledge, skills and time. As contractors and subcontractors are often under pressure to meet project deadlines, there was no sufficient time for developing the BIM competence required. For similar reasons, there was also no time for continuous and complete updating of the models.

Secondly, in terms of legal framework, there are still uncertainties of the legal responsibilities. For example, a BIM server is expensive. There is also an issue of maintenance costs. Thus, the server will have to be put into the contract for the project. There are also issues of intellectual property from, and ownership of, the BIM developed in earlier stages of the project, as well as responsibility for errors in the BIM. Furthermore, when the project ends, there is a question of who should take ownership of the BIM on the project. Most of the firms interviewed suggested that it would be most appropriate for the client to take ownership of the BIM models.

Some consultants and contractors acknowledged that there is a need to align what the developers want with what the project team can deliver. Many consultants were still not ready to meet the developers' expectations; such as the need to launch the sale of units in the project as soon as possible. Some contractors and consultants also provided the feedback that they were not ready for a full-scale BIM implementation. Hence, some contractors and consultants proposed that BIM should be implemented in stages. There was a need for all project participants to collaborate effectively. All in all, the interviewees suggested that developers should take the lead in the process of developing and using the BIM, but have realistic expectations from the project teams.

Thirdly, there were technical issues. Those which were most commonly encountered by interviewees were: interface issues, the loss of information when transferring the models from one software to another, licenses, bandwidth and security. One technical issue that was commonly encountered by the industry was because BIM models were created using different versions of the popular software. If the models had been prepared using earlier versions of the software, which are no longer available in the market, there will be some productivity loss due to the time spent contacting the manufacturer directly to obtain the particular version of the software before they were able to gain access to the models.

Another example was when one contractor was trying to transfer the BIM models to another party. They were discussing with the BIM vendor on how to transfer the models without losing much information. However, the BIM vendor was unable to resolve the issues. As a result, the other party had to use BIM models which were not the most comprehensive; a considerable amount of time was needed to put in additional information before the BIM models could be used by the other party.

Some other difficulties encountered were because the BIM models were of low level of detail. Hence, a great deal of time and effort was needed to improve the quality of the models so that rule-checking and quantity calculation could be performed.

4. Proposed Intelligent System for Productivity and Safety Improvement

Realising the challenges that the Singapore construction industry faced, an intelligent system has been developed which incorporates both productivity and safety performance, using BIM as the platform. The proposed system is the key deliverable of a research project funded by the

Ministry of Manpower, Singapore. The system, named Intelligent Productivity and Safety System (IPASS), was designed to provide a solution to improve productivity and safety performance by addressing the challenges and creating opportunities for the industry to maximise the benefits of BIM (Figure 4). IPASS enables collaboration among the project stakeholders as they analyse the productivity and safety performance before the start of a project. The system comes with a BIM modelling guide which specifies the method of inputting information in some detail. Thus, it will help to minimise disputes and improve the level of details of the BIM models developed by the consultants and contractors.

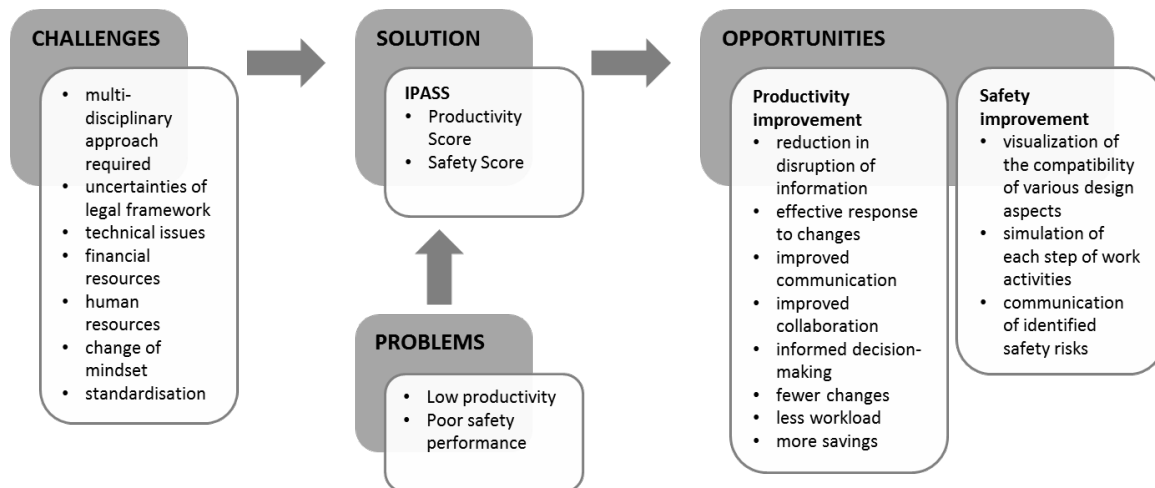


Figure 4. The development of IPASS as one of the solutions which can overcome the problems and challenges faced by the industry and create opportunities.

The system is also able to act as a monitoring tool for productivity and safety performance as the project progresses. IPASS automatically identifies safety hazards and provides solutions to mitigate the identified hazards. IPASS also allows the users to apply different structural and wall systems and see how they affect the buildability score individually or in combination, and to work to achieve the targeted score. Hence, during different stages of a construction project (pre-construction, design and construction stages), IPASS is able to help designers look at and improve the productivity and safety aspect of the design of a building. BIM models generated will help to visualize the different scenarios, enabling continuous productivity and safety monitoring.

The productivity score is computed based on the Buildable Design Score (BD Score) of the BCA's Buildable Score Assessment System (BDAS). The BD Score of a project is made up of three parts: Structural System (maximum 45 points), Wall System (maximum 45 points) and Other Buildable Design Features (maximum 10 points). The maximum productivity score achievable is 100 points. The BDAS was developed by the BCA as a means to measure the potential impact of a building design on the usage of site labour (BCA, 2014). Over the years, BCA has increased progressively the minimum BD score for building plan approval; this is aimed at boosting productivity. Hence, it is necessary for designers to include more productive technologies and standard components in the building design.

The safety score is computed based on the prevention and control of hazards detected in the structural systems and wall systems, and the Construction Safety Audit Scoring System (ConSASS) assessment. ConSASS is a tool to measure the maturity of the WSH system which includes its documentation and implementation, aiming at providing a standardized scoring system for the construction industry (MOM, 2013). ConSASS is aimed to provide an easy comparison between construction sites in term of their effectiveness in managing safety and health risks. ConSASS consists of an audit checklist and a score card. The audit checklist is derived from the Singapore Standards for Occupational Safety and Health Management System (SS506), Code of practice for safety management systems for construction worksites (CP 79) and the Universal Assessment Instrument (UAI) published by the American Industrial Hygiene Association (AIHA). The questions in the checklist are grouped into bands, from Band I to IV, in order to reflect the increasing level of maturity of the elements being audited. The results are tabulated in the score card, which shows the maturity of the different elements in the Occupational Safety and Health Management System (OSHMS).

The maximum safety score that can be achieved based on the prevention and control of hazards is 90 (maximum 45 points for the structural system and maximum 45 points for the wall system). ConSASS assessment is taken into consideration by giving the building a score for each band attained (from Band I to IV). The maximum score that can be achieved through ConSASS assessment is 10, which is when the building under assessment could achieve the highest band (Band IV). The maximum safety score achievable from the prevention and control of hazards as well as ConSASS assessment is 100 points. The full details on the development of the system can be found in other paper/s.

5. Conclusion

The Singapore government is playing an important role in leading the industry construction industry in adopting BIM through the first and second BIM roadmap, launched in 2010 and 2014 respectively. The roadmap put in place a number of strategies necessary for BIM implementation in the industry. However, it would appear that many firms in the construction industry in Singapore have yet to utilise BIM to its maximum potential. There are a lot of opportunities to utilise BIM for more strategic and important tasks than the current application for visualisation and meeting the requirements of building plan submissions.

The paper highlighted three challenges commonly encountered by the local firms. Firstly, successful BIM implementation requires a multi-disciplinary approach, but many players are still not ready for full collaboration since developing a useful BIM model requires sharing of information and specifications in great details. Secondly, there are still uncertainties of the legal responsibilities. The firms were still unclear about maintenance costs and the ownership of the BIM. Thirdly, there are still some important technical issues that have to be solved.

To bring BIM and its application to a higher level, it is essential to address those challenges. BCA had been trying to address some of the challenges. The second BIM Roadmap focuses on this. BIM can be utilised at a more advanced level when the construction industry has addressed

the more fundamental issues. Some suggestions include involvement of all project stakeholders (rather than leaving it to the authority); initiatives and drive towards process transformation; and closer collaboration between consultants and contractors so that BIM can be utilised to achieve higher productivity and safer projects in the construction industry.

To address the challenges, an intelligent system has been developed which incorporates both productivity and safety performance, using BIM as the platform. The system, IPASS, was designed to provide solutions for the challenges and create opportunities for the industry to derive greater benefits from BIM. It was developed in line with the second BIM roadmap which emphasises collaboration to achieve higher productivity. IPASS enables collaboration among the project stakeholders as they analyse the productivity and safety performance before the start of a project. The system is also able to act as a monitoring tool for productivity and safety performance as the project progresses.

6. Acknowledgements

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What Hinders the BIM Adoption in Singapore: An Empirical Study

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Abstract

Building information modelling (BIM) has been seen as one of the most promising recent developments in the architecture, engineering, and construction (AEC) industry as well as a revolutionary change for managing a project from beginning to end. The Singaporean government has promoted the use of BIM in the AEC industry to help firms improve their productivity. The objectives of this study are to investigate the BIM adoption status and to identify the hindrances to BIM adoption in Singapore. To achieve the objectives, a preliminary questionnaire survey was performed with 34 professionals. A BIM adoption index (BIMAI) was proposed to measure the extent of BIM adoption. The low average BIMAI implied that the BIM adoption in the Singaporean AEC industry was still immature. Consultants were found to have a higher level of BIM adoption than contractors. Additionally, three-dimensional presentation, clash detection, design coordination, and construction system design were found to be the functions that were significantly applied in practice. Furthermore, the statistical analysis results showed that the mean scores of hindrances ranged from 3.79 to 2.65. Nine of the 20 hindrances were statistically significant, and thus were considered as critical hindrances to BIM adoption in the Singaporean AEC industry. “Lack of subcontractors who can use BIM technology”, “cost of investment”, and “lack of demand for BIM use” were the top three hindrances. This study provides an understanding of the BIM adoption status in Singapore and allows the practitioners to take measures to reduce the critical hindrances.

Keywords: Building information modelling (BIM), hindrances, construction projects, Singapore.

1. Introduction

Building information modelling (BIM) has been seen as one of the most promising recent developments in the architecture, engineering, and construction (AEC) industry (Azhar, 2011). BIM is defined as “a set of interacting policies, processes and technologies generating a methodology to manage the essential building design and project data in digital format throughout the building’s lifecycle” (Succar, 2009, pp. 357). This definition highlights BIM’s holistic nature, which covers not only software that allows the geometrical modelling and the input of information but also project management-related tools and processes (Bryde et al., 2013). In reality, BIM has been seen as a revolutionary change for managing a project from beginning to end (Chen et al., 2013). It requires the use of information and communication technology (ICT) to simulate the planning, design, construction and operational phases of a building project (Azhar, 2011), in order to provide a safer and more productive environment for users, to assert the minimum impact on environment from its existence, and to be more operationally efficient for the owner throughout the project lifecycle (Arayici and Aouad, 2010).

Application areas of BIM include, but are not limited to site analysis, design option analysis, 3D presentation, design coordination, cost estimating, energy simulation, clash detection, construction system design, schedule simulation, quantity takeoff, site resource management, and offsite fabrication (Azhar, 2011, Bynum et al., 2013, Cao et al., 2014, Eastman et al., 2011, Li et al., 2012, Monteiro et al., 2014). Previous studies have identified a number of benefits that may be brought by BIM adoption. According to a recent study by McGraw Hill Construction (2014) in Australia and New Zealand, the most significant short-term benefits were reduced errors and omissions, enhancement of organization’s image as an industry leader, reduced rework, and the most significant long-term benefits were maintained repeat business, reduced project duration and reduced construction cost. In terms of time saving, Autodesk (2008) argued that Revit® Architecture software saved 91% of the time on checking and coordination and 50% on design development, compared with traditional Computer Aided Design (CAD) tools.

In Singapore, the Building and Construction Authority (BCA) and buildingSMART Singapore have been promoting the use of BIM in the construction industry because BIM is identified as a key technology that will enhance productivity and integration across diverse disciplines in the construction value chain. In 2010, BCA initiative the BIM Roadmap with the ambitious target that at least 80% of the construction industry uses BIM by 2015. To achieve this target, one strategy is to introduce the legal provision to mandate BIM-based plan submission (Teo et al., 2015). Since 2013, mandatory BIM electronic submission has been introduced in phases. Thus, it is compulsory for practitioners to submit architectural or engineering plans in the BIM format for regulatory approval.

Despite the efforts from the government and industry, the BIM adoption in Singapore still faces some hindrances and challenges. The objectives of this study are to investigate the BIM adoption status and to identify the hindrances to BIM adoption in the Singaporean construction projects. This study provides an understanding of the status quo of the BIM adoption in Singapore and critical hindrances, which allows the government and practitioners to develop

strategies to reduce these hindrances and further promote the use of BIM in the construction industry.

2. Background

2.1 BIM in Singapore

In recent years, the government of Singapore, through the BCA, has highlighted productivity in the construction industry, and initiated a Construction Productivity Roadmap to transform the construction industry and raise its productivity (BCA, 2011b). Because of the potential to enhance construction productivity, driving BIM adoption has been seen as one strategic thrust (Teo et al., 2015). In 2011, a National BIM Steering Committee was set up to provide a governing framework to steer the implementation of the BIM Roadmap (BCA, 2011a), and led the development of the “Singapore BIM Guide” and “BIM Particular Conditions” (BCA, 2013).

To encourage the BIM adoption in Singaporean AEC industry, BCA (2011b) has provide a series of initiatives. For example, BCA and buildingSMART Singapore developed BIM submission templates, a library of design objects and project collaboration guidelines. In 2011, pilot projects with BIM were performed with the public sector clients. Subsequently, BCA issued regulations to make it compulsory for practitioners to submit architectural, structural as well as mechanical and electrical plans for building works for approval in the BIM format (BCA, 2015). Specifically, after 1 July 2013, all architectural plans of new building projects with gross floor area of more than 20,000 m² must be submitted in the BIM format; after 1 July 2014, all the engineering plans of new building projects with gross floor area above 20,000 m² must be submitted in the BIM format; and after 1 July 2015, all plans of new building projects with gross floor area above 5,000 m² must be submitted in BIM format. In addition to the regulations, BCA also set up the BIM Fund, which is aimed to help firms establish BIM collaboration capability by covering the costs for training, consultancy services and purchase of hardware and BIM software (BCA, 2014).

2.2 Hindrances to BIM adoption

Although the benefits of BIM have been recognized within the AEC industry and the technology supporting BIM has grown matured, BIM adoption has been slower than anticipated (Bernstein and Pittman, 2004). Thus, a number of studies have been performed to identify the factors influencing BIM adoption (Cao et al., 2014). Most of these studies have focused on the industry professionals’ perceived hindrances to the diffusion of BIM in the industry (Eadie et al., 2013, Howard and Björk, 2008). In Australia, Gu and London (2010) indicated that the lack of experience in BIM due to a limited understanding of the industry needs and technical requirements was a major hindrance to the advancement and adoption of BIM related technologies within the Australian AEC industry. Additionally, Gerrard et al. (2010) found that lack of BIM expertise, lack of awareness and resistance to change were the main barriers to BIM adoption. A more recent study by Alabdulqader et al. (2013) reported that BIM were not well adopted mainly because practitioners perceived the existing CAD system can fulfil the

need and BIM was expensive to operate and maintain. Through a literature review, a total of 20 hindrances to BIM adoption were identified, as shown in Table 1.

Table 1: Identification of hindrances to BIM adoption

<i>Code</i>	<i>Hindrances</i>	<i>References</i>
H01	<i>Cost of investment</i>	<i>(Bernstein et al., 2012, D'Agostino et al., 2007, Eadie et al., 2013, Eastman et al., 2011, Gilligan and Kunz, 2007, Khosrowshahi and Arayici, 2012, Ku and Taiebat, 2011, Tse et al., 2005, Won et al., 2013, Yan and Damian, 2008, Young et al., 2009)</i>
H02	<i>Learning curve for BIM technologies</i>	<i>(Bernstein et al., 2012, D'Agostino et al., 2007, Demian and Walters, 2013, Eastman et al., 2011, Gilligan and Kunz, 2007, Krygiel et al., 2008, Ku and Taiebat, 2011, Won et al., 2013, Yan and Damian, 2008, Young et al., 2009)</i>
H03	<i>Lack of support from senior management</i>	<i>(Bernstein et al., 2012, D'Agostino et al., 2007, Gilligan and Kunz, 2007, Won et al., 2013)</i>
H04	<i>Design liability issues</i>	<i>(Bernstein et al., 2012, D'Agostino et al., 2007, Eastman et al., 2011, Gilligan and Kunz, 2007, Khosrowshahi and Arayici, 2012, Won et al., 2013)</i>
H05	<i>Data ownership issues</i>	<i>(Azhar, 2011, Becerik-Gerber and Kensek, 2010, D'Agostino et al., 2007, Dossick and Neff, 2010, Eadie et al., 2013, Gu and London, 2010)</i>
H06	<i>Poor collaboration among participants</i>	<i>(D'Agostino et al., 2007, Eastman et al., 2011, Ku and Taiebat, 2011, Won et al., 2013)</i>
H07	<i>Poor interoperability among BIM software</i>	<i>(Becerik-Gerber and Kensek, 2010, D'Agostino et al., 2007, Demian and Walters, 2013, Eastman et al., 2011, Grilo and Jardim-Goncalves, 2010, Gu and London, 2010, Ku and Taiebat, 2011, Won et al., 2013, Young et al., 2009)</i>
H08	<i>Reluctance to openly share information</i>	<i>(Becerik-Gerber and Kensek, 2010, Eadie et al., 2013, Gilligan and Kunz, 2007, Won et al., 2013, Young et al., 2009)</i>
H09	<i>Lack of relevant training</i>	<i>(Becerik-Gerber and Kensek, 2010, Gu and London, 2010, Khosrowshahi and Arayici, 2012)</i>
H10	<i>Unsupportive organizational structure</i>	<i>(Eastman et al., 2011, Won et al., 2013)</i>
H11	<i>Unsupportive organizational culture</i>	<i>(Becerik-Gerber and Kensek, 2010, Eadie et al., 2013, Jensen and Jóhannesson, 2013, Khosrowshahi and Arayici, 2012)</i>
H12	<i>Lack of subcontractors who can use BIM technology</i>	<i>(Won et al., 2013, Young et al., 2009)</i>
H13	<i>Data security issues</i>	<i>(D'Agostino et al., 2007, Gu and London, 2010, Won et al., 2013)</i>
H14	<i>Lack of relevant expertise and knowledge</i>	<i>(Becerik-Gerber and Kensek, 2010, Eadie et al., 2013, Gilligan and Kunz, 2007, Khosrowshahi and Arayici, 2012, Tse et al., 2005, Won et al., 2013, Young et al., 2009)</i>
H15	<i>Limitation of current BIM applications</i>	<i>(Gilligan and Kunz, 2007, Won et al., 2013, Young et al., 2009)</i>

H16	<i>Lack of industry standards</i>	<i>(D'Agostino et al., 2007, Eastman et al., 2011, Young et al., 2009)</i>
H17	<i>Lack of BIM implementation data in construction phase</i>	<i>(Eastman et al., 2011, Won et al., 2013, Young et al., 2009)</i>
H18	<i>Perception that current technology is enough</i>	<i>(Yan and Damian, 2008)</i>
H19	<i>Lack of tangible benefits</i>	<i>(Becerik-Gerber and Kensek, 2010, D'Agostino et al., 2007, Gu and London, 2010, Khosrowshahi and Arayici, 2012, Won et al., 2013)</i>
H20	<i>Lack of demand for BIM use</i>	<i>(Eadie et al., 2013, Khosrowshahi and Arayici, 2012)</i>

3. Method and Data Presentation

A large research project that attempts to investigate BIM adoption in the AEC industry in Australia, Singapore and China has been implemented. In this study, a preliminary questionnaire survey was performed to investigate the status quo and critical hindrances to BIM adoption in Singapore. The comprehensive literature review supported the development of the questionnaire. In the survey, the respondents were asked to rate the extent of adopting the areas of BIM in their organizations, and the influence of the 20 hindrances on ERM implementation using a five-point scale (1=very low, 2=low, 3=neutral, 4=high, and 5=very high). In addition, they were requested to provide general information, such as their firm type, years of industry experience, designation, and years of BIM experience of their firms. Furthermore, they were asked to provide the number of the projects that their firms had undertaken in the past five years as well as the number of the projects where BIM were adopted.

The population consisted of all the industry practitioners in the Singaporean AEC industry. As there was no sampling frame in this survey, the sample was a non-probability sample. The non-probability sampling can be used to obtain a representative sample (Patton, 2001), and has been recognized as appropriate when the respondents were not randomly drawn from the entire population, but were rather selected based on whether they were willing to participate in the study (Liu et al., 2016, Wilkins, 2011, Zhao et al., 2013).

A total of 130 questionnaires were sent out and 34 completed questionnaires were received, yielding a response rate of 26%, which was acceptable compared with the norm of 20–30% with most questionnaire surveys in the construction industry (Akintoye, 2000, Hwang et al., 2015). In spite of a relatively small sample size, statistical analysis can still be carried out because the central limit theorem holds true when the sample size is greater than 30 (Ott and Longnecker, 2001). The profile of the respondents is shown in Table 2. Out of the 34 respondents, 79% were from contractors while 21% were from consultants, including design firms. In terms of experience, 50% had more than 10 years of industry experience, demonstrating the reliability of the data collected from the survey. In addition, 47% of the respondents had more than two years of experience in BIM. Because the electronic submission of architectural plans began to become mandatory after 1 July 2013, it has been around two years since most firms started to adopt BIM. Thus, it was not surprising that 35% had adopted BIM less than two years. Six firms did

not have BIM experience. There may be two reasons for this. First, these firms perform only small projects, for which electronic submission in the BIM format for approval was not mandatory. Second, they outsourced BIM-related tasks to BIM moulders or specialists to satisfy the mandatory requirements from BCA.

Table 2: Profile of respondents and their firms

Organization type	N	%	Industry experience	N	%	BIM experience	N	%
Contractor	27	79%	5-10 years	17	50%	None	6	18%
Consultant	7	21%	11-15 years	11	32%	1- 2 years	12	35%
			16-20 years	4	12%	3-4 years	12	35%
			Over 20 years	2	6%	5 years and more	4	12%

4. Results

4.1 Status quo of BIM adoption

To measure the extent of BIM adoption in firms, a BIM adoption index (BIMAI) is proposed in this study as follows:

$$\text{BIMAI} = \text{No. of projects with BIM adoption} / \text{Total no. of projects of a firm} \times 100\%$$

In this study, the denominator of this equation was the total number of the projects that a firm had undertaken in during the past five years. Thus, the BIMAI of each company surveyed was calculated (see Table 3).

Table 3 shows that the BIMAI of contractors was 26% while that of consultants was 42%. The overall average BIMAI was 30%. These results implied that the BIM adoption in the Singaporean AEC industry was still immature. Consultants, including those BIM specialists and design firms, had a higher level of BIM adoption than contractors. Only three out of the 27 contractors (11%) received BIMAI over 50%

Table 3: Status quo of the BIM adoption in Singapore

BIMAI	Contractor	Consultant	Overall	
			No.	Percentage
0%	5	1	6	18%
10-19%	7	1	8	24%
20-29%	4	0	4	12%
30-39%	4	0	4	12%
40-49%	4	2	6	18%
50-59%	1	1	2	6%
60-69%	2	1	3	9%
90-100%	0	1	1	3%
Total	27	7	34	100%
Mean	26%	42%	30%	

In terms of application areas of BIM, 14 areas were identified from literature review (Azhar, 2011, Bynum et al., 2013, Cao et al., 2014, Eastman et al., 2011, Li et al., 2012, Monteiro et al.,

2014) and presented in the survey. The one-sample t test was used to check whether these areas were significantly applied (see Table 4). Only four areas (three-dimensional presentation, clash detection, design coordination, and construction system design) received mean values above 3 and p-values below 0.05, suggesting that these four areas had been significantly applied in the Singaporean AEC industry. This result was consistent with the low overall BIMAI in Singapore.

Table 4: Application areas of BIM

<i>Application areas</i>	<i>Description</i>	<i>Mean</i>	<i>Rank</i>	<i>P-value</i>
<i>Site analysis</i>	<i>Analyzing project site location</i>	2.38	9	.001*
<i>Analyzing design options</i>	<i>Exploring and comparing design options based on three-dimensional models</i>	3.18	5	.362
<i>Three-dimensional presentation</i>	<i>Three-dimensional presentation of complex structures to nonprofessionals</i>	4.26	1	.000*
<i>Design coordination</i>	<i>Coordinating design of architectural, structural, as well as mechanical, electrical, and plumbing systems</i>	3.65	3	.002*
<i>Cost estimating</i>	<i>Project cost estimating during design stage</i>	2.76	7	.274
<i>Energy simulation</i>	<i>Analyzing building's energy distribution and consumption</i>	1.94	13	.000*
<i>Other performance simulations</i>	<i>Analyzing building's other performances such as lighting, acoustics, air flows, and pedestrian circulation</i>	2.06	12	.000*
<i>Clash detection</i>	<i>Checking conflicts among building systems prior to construction</i>	3.85	2	.000*
<i>Construction system design</i>	<i>Designing and analyzing the construction of complex building systems in order to increase planning</i>	3.41	4	.021*
<i>Schedule simulation</i>	<i>Simulating master schedules and construction sequences</i>	3.09	6	.675
<i>Quantity takeoff</i>	<i>Quantity takeoff and cost estimation during construction stage</i>	2.74	8	.255
<i>Site resource management</i>	<i>Integration with schedules and onsite information to manage the storage and procurement processes of project materials and equipment</i>	2.29	10	.001*
<i>Offsite fabrication</i>	<i>Generating digitized information to facilitate greater use of prefabricated components</i>	2.24	11	.001*

* The one-sample t test results are significant at the 0.05 level (test value=3).

4.2 Critical hindrances to BIM adoption

To enhance the level of BIM adoption, critical hindrances should be identified and addressed. The one-sample t test was used to check whether the 20 hindrances had significantly negative influence on BIM adoption in the Singaporean AEC industry (see Table 5). The mean scores of hindrances ranged from 3.79 to 2.65. A total of nine hindrances received mean values above 3 and p-values below 0.05, implying that they were deemed as critical hindrances to BIM adoption.

“Lack of subcontractors who can use BIM technology” received the top rank (mean=3.79), indicating that it was not sufficient to promote BIM adoption in only main contractors. Subcontractors, which were also important participants in construction projects, also have to be involved in the trend of BIM adoption. However, the subcontractors were likely to undertake small projects that did not face mandatory requirements for BIM submission, and thus do not have incentives to adopt BIM.

“Cost of investment” was ranked second (mean=3.74), suggesting the costs associated with BIM were still a great concern of the AEC industry practitioners in Singapore. Although BCA has set up the BIM Fund that may be used to cover the costs for training, consultancy services and purchase of hardware and BIM software (BCA, 2014), there were also specific requirements for the applicants. Thus, some firms may not be eligible for the BIM Fund and have to bear the costs on their own.

Table 5: Critical hindrances to BIM adoption in Singapore

Code	Mean	Rank	P-value	Code	Mean	Rank	P-value
H01	3.74	2	.000*	H11	3.44	9	.023*
H02	3.47	8	.001*	H12	3.79	1	.001*
H03	3.62	4	.004*	H13	2.65	20	.032*
H04	2.79	18	.269	H14	3.62	4	.001*
H05	3.26	11	.173	H15	3.18	14	.362
H06	3.26	11	.221	H16	2.79	18	.228
H07	2.79	18	.228	H17	3.18	14	.280
H08	2.97	16	.845	H18	3.59	6	.009*
H09	3.29	10	.143	H19	3.59	6	.006*
H10	3.21	13	.214	H20	3.65	3	.001*

* The one-sample t test results are significant at the 0.05 level (test value=3).

“Lack of demand for BIM use” occupied the third position (mean=3.65), implying that the actual demand for BIM in the industry was not as great as the government thought. Indeed, the government recognizes BIM adoption as one of the strategic thrusts that can significantly raise the productivity in the construction industry. Thus, the government should use the potential benefits from BIM to convince industry practitioners that it is really necessary to use BIM to replace two-dimensional CAD.

5. Conclusions and recommendations

Building information modelling (BIM) has been seen as one of the most promising recent developments in the architecture, engineering, and construction (AEC) industry as well as a revolutionary change for managing a project from beginning to end. The Singaporean government has promoted the use of BIM in the AEC industry to help firms improve their productivity. The objectives of this study are to investigate the BIM adoption status and to identify the hindrances to BIM adoption in Singapore. To achieve the objectives, a questionnaire survey was performed with 34 professionals. The low average BIMAI implied that the BIM adoption in the Singaporean AEC industry was still immature. Consultants had a higher level of BIM adoption than contractors. Additionally, three-dimensional presentation, clash detection, design coordination, and construction system design were found to be the functions of BIM that were significantly applied in practice. Furthermore, nine hindrances were recognized as critical hindrances and should attract more attention from the government. “Lack of subcontractors who can use BIM technology”, “cost of investment”, and “lack of demand for BIM use” were the top three hindrances.

There are limitations to the conclusions. First the identification of the hindrances may not be exhaustive with the passage of time. Additionally, the sample size was relatively small in this

preliminary survey, so cautions should be warranted when the analysis results are interpreted and generalized. Moreover, the single-source data are very likely to cause common method biases (Jiang and Jiang, 2015, Jiang and Wang, 2014), which is a common limitation of the studies using questionnaire survey (Zhao et al., 2016). Furthermore, the findings of this study are interpreted in the context of Singapore, which may be different from the context of other countries.

Future studies would investigate the interaction mechanisms among the hindrances to BIM adoption, and identify the influence paths comprised by some of these factors. Also, as BIM adoption may involve changes in firms, organizational change theories would be used to interpret the critical hindrances and provide the theoretical rationale behind these interaction mechanisms.

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Improving safety at building construction sites by means of BIM and mobile tools

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Abstract

Building Information Model (BIM) based designs, plans, drawings and other information needed on construction sites can be used more and more by mobile devices as hardware, software and cloud-based data sharing are developing rapidly. As a result, the safety information can also be "mobilized". If compared to the traditional safety documents, the mobile versions provide more efficient workflow and possibility to completely new kind of information contents. However, the most important benefits will likely be, that safety information can be brought closer to the production event, where it can genuinely affect occupational site safety. Additionally, up-to-date safety level information including safety violation statistics can be provided for site management purposes, and this safety data is automatically stored for later analysis and development purposes.

Mobile opportunities have been implemented to safety purposes in limited extent this far. This research aims to clarify the possibilities of useful mobile tools and promising new ways of delivering BIM-based information needed at field. Results are based on an analysis focused on 1) the different types of mobile applications currently available for safety purposes, 2) the most promising new ways of sharing and recording safety related information at site using mobile devices, and 3) the apparent potential of mobility in construction safety management. Data was collected by literature study, experience got by hands-on software testing, and interviewing and discussing with industry representatives in various meetings related to an on-going collaborative research and development project. The goal of the research project is to develop publishing, management and usability of digital building information by web-based solutions and procedures in the construction supply chain.

The identified most promising mobile opportunities for improving the occupational site safety will be tested in a real on-going building construction project. Selection of use cases will be carried out by the involved development project partners, including software vendors, research institutes and industry representatives such as a general contractor, precast fabricator and

structural engineering company. Experience will be used to take advantage of BIM and mobile tools more efficiently on construction sites in the future, and to encourage software houses to develop the needed final more suitable applications for the industry.

Keywords: occupational safety, building construction site, mobile information, BIM, mobile safety management

1. Introduction

Building Information Modelling (BIM) is very current topic worldwide. Reasons for increasing BIM implementation are demands from governments/building authorities, demand from big conscious client organizations, competitors' good experience in BIM as a tool to support and intensify the design and construction processes, the emergence of common national BIM guidelines to standardize the main principles and procedures in projects, the general global digitalization in construction industry, and simply the identified business opportunities related to BIM. The current fast construction digitalization is highlighted e.g. in a summary of BIM adoption around the world published by Construction Management magazine (CIOB 2015). Examples of reported safety related uses of BIM in building construction sector are BIM-based 3D site layout and fall prevention planning, and BIM-based workflow visualization and analyses including hazard identification (Sulankivi 2014). In a survey conducted by McGraw Hill Construction in US (2013), a large percentage (43%) of the firms that use BIM reported that BIM use has a positive impact on safety.

In the construction industry, ICT systems were designed for stationary office use, but have been pushed out to the production environment, which have resulted in that construction management teams are tied up inside the site offices at their desktop computers a large part of their working hours (Löfgren 2007). According to previous research, construction management personnel have a clear need to use digital information while at field, not in the site office only (Lemmetty 2013). Now, after mobile technology has become an essential part of our everyday life, it's rolling into professional use as well, improving e.g. the access to construction documentation and other production information for site staff. Löfgren (2007) describes how Skanska, one of the largest building companies in the world, become among the first ones interested in mobile ICT as a result of identifying problems related to the overwhelming quantity and poor quality of information in the field in a US construction project 2005. The collaborative effort between a software developer and the production management team in the project resulted in improved understanding of the limitations of existing technology and the generation of new tools that were more useful to the construction site environment. Good experience in mobile ICT got in Skanska US led rapidly to a global development initiative involving e.g. Sweden, UK, Norway and Finland. Focus was first on the management of drawings and specifications used on construction sites, but soon mobile tools and procedures started to be developed to replace existing administrative on-site work processes as well. Also according to Fender & Wolfley (2014) portable electronic devices such as tablets and smartphones can be useful for safety professionals, and the right apps can improve efficiency and tablets can pay for themselves quickly.

As a result of rapid development of hardware, software and cloud-based data sharing, also BIM-based designs and other new kind of information needed on construction sites can be used more and more by mobile devices. However, mobile opportunities have been implemented to safety purposes in a limited extent this far. This research aims to clarify the possibilities of further digitalization by identifying useful mobile tools and promising new ways of delivering BIM-based plans and other information needed at field. Several current mobile hardware and

software can serve construction project management as a whole, including safety, but this paper introduces new mobile opportunities from the specific viewpoint of occupational site safety, the final target being to bring relevant safety information closer and more easily available in the production events and site management procedures, where it is needed to conduct the construction work safely.

2. Research method

Results are based on an on-going collaborative research and development project, which main goal is to develop publishing, management and usability of digital building information by web-based solutions and procedures. Results presented in this paper aim to promote safety management from the same information sharing aspects as construction production management as a whole is being developed in the research project.

Potential new technology and exploitation possibilities have been analysed based on information got by literature study, surveying available mobile applications intended or suitable for building construction industry, studying and testing the features of these applications, discussing about the needs and expectations of e.g. site staff with the research project partners in various meetings, and by individual interviews. Beside research organizations, industry representatives such as a general contractor and a precast concrete manufacturer, engineering companies, as well as software developers providing and developing both BIM-based and mobile applications for construction industry are involved in the research and development project. Based on the collected information, this analysis considers practical safety information needs at field, possibilities of the newest mobile or BIM-based software, as well as the found leading edge mobile work flow and procedures.

Selected most promising new mobile opportunities for improving the occupational site safety will be studied in more detailed level and tested in a real on-going construction project. If a suitable tool or a prototype for a specific need is not available for testing, research organizations will demonstrate the needs to software house representatives to encourage them to develop the needed final applications for market.

3. Results

3.1 Mobile technology for site safety

After surveying available web-based/cloud-based mobile applications intended or suitable for building construction industry, those including some kind of safety related features were analysed in more detailed level and 4 different kind of categories of applications identified. These different types of mobile safety related applications are presented in Table 1 together with few examples of real tools of each type.

Table 1: Examples of different types of mobile safety related applications.

Types	Examples of existing mobile tools
1: Construction project management applications including safety related tools	Trimble ProjectSight, Autodesk 360 Field, bim+ Connect, Aconex, Procore construction management software, PlanGrid
2: Safety auditing or safety level inspection/measurement/rating apps	iAudit, iOSHA Process Safety Management Auditing, Trimble Inspector, Kotopro TR-mittaus, T3, InstaAudit
3: Applications for a single specific purpose	Dakota's EHS Pocket Guide, ChemAlert, iTriage, Clinometer HD, SoundMeter, DMD Panorama, Tekla Field3D, Safety Coach
4: Applications meant for a specific construction phase or work	Daily Reports (e.g. for concrete work), Concrete calculator, Fall PtD, Raksamittari PRO

The first type, *construction project management applications including safety related features*, are comprehensive project management or collaboration solutions typically aiming to connect the office to the field, as described by Trimble (Lavine 2015), as well as distributing/sharing up-to-date project documentation and information regardless of time and physical location of the user. At site office or headquarters these solutions can be used by PC using a web browser as the user interface. At field, mobile device such as iPad or a mobile phone is usually used together with the corresponding mobile application installed to the device. That's why they are usually tied to a specific operating system such as Windows, Android or iOS, but some applications are available for several operating systems. However, when a browser is the interface in the mobile device also, the application is available to all devices with internet connectivity regardless of the operating system.

The second type of applications are developed for systematic and effective *mobile site safety auditing or safety level inspection/measurement/rating*. As a result of cultural differences in safety regulations and inspection procedures, these are typically country-specific applications. For example, "Kotopro TR-mittaus", "T3" and "Insta Audit" are based on a Finnish method to calculate the weekly safety level, serving the Finnish building construction sector only. In turn there is e.g. an US application called "iOSHA Process Safety Management Auditing" based on US regulations. On the other hand, there could be some good ideas related to the mobile application or the original auditing process, which might be useful to be transferred from one country (and application) to another.

The third type of applications are developed for *a single specific purpose* such as issue management, browsing H&S regulations, checking employee qualifications, searching chemical data or medical information, measuring site conditions, as well as viewing 3D building information models. Issue management applications included in this group can typically be used for many different purposes and even in different industries and could thus be called "general issue management solutions". The fourth type, applications meant for a *specific construction phase or work*, include mobile tools for flooring or concrete pouring, for example, and include some safety related features just for these specific work tasks.

If considering all different available mobile applications, one typical common feature is the possibility to use them off-line. This is important at building construction site, where internet connection can't be guaranteed all the time. The main principle is that e.g. recording issues and other work at field can be conducted off-line, and uploaded to the cloud-based project database when possible. Another common feature is, that the applications typically indicate if there is updates available to the project data stored into tablet, but the user decides if updates are downloaded instantly or later using better internet connection or to avoid disturbance for the work task going on at the moment, for instance.

3.2 Exploitation of Mobile devices and Safety data on site

Exploitation of mobile devices is relatively new phenomenon in construction sites. According to interviews performed in a Finnish construction company, at the moment the biggest issue concerning mobilization is the implementation of the new procedures into production. However, more and more applications are being released and software houses are constantly developing more user friendly applications, in order to help the implementation into construction sites. This on-going research project is encouraging software houses into development by evaluating mobile applications together with construction companies.

Similar to organizations in other industries construction and engineering organizations are leveraging mobile and wireless solutions to address the need for greater collaboration among a highly mobile and distributed workforce (Krebs 2009). Many mobile tools have also been tested for different kind of safety related purposes already, including sharing project designs and plans, recording and documenting safety observations, browsing safety data and guidelines, and various safety related measurements and calculations. Summary of found different kind of uses for mobile tools in context of safety management is presented in table 2, and the use cases are visualized by practical examples of possible utilization.

By the interviews carried out in the Finnish construction company, this research aimed to determine the utilization rate and user experience of mobile devices. One of the main findings was, that a safety level inspection application is considered the most valuable applications concerning occupational safety in the company at the moment. Production management personnel stated that it genuinely provides effective tool to audit safety level, and the additional features such as action assignment and automatic follow-ups were appreciated highly/evaluated useful. The possibility to assign task or notification to the responsible person by email straight from the application is not only saving time but making production management more efficient. Previously this whole procedure been conducted using pen and paper, and it must have been transferred to digital format after the inspection. As a result of using a mobile device, the inspection and reporting is completed once during the inspection tour, which saves time significantly. Mobile devices can be used also to take photos and attach them to the inspection report, making the documentation and positioning more accurate. At the moment, general contractors use mobile tools more than their sub-contractors/special contractors. As a result, there is still need to deliver information by e-mail to most of the subs, but in the future they will be provided an access to a web-based system to e.g. record safety notices and to get

notifications of issues assigned to them. On the whole, the goal is to make safety observations available to all workers at the site, not only to the production management personnel.

Table 2: Safety related use cases of mobile applications.

<i>Use case</i>	<i>Short description or practical example of possible use</i>
<i>1. Project and Safety document sharing</i>	<i>Documents needed at field are carried along digitally in a mobile device or accessed on-line by web.</i>
<i>2. Viewing BIM-based construction and safety plans</i>	<i>Reviewing e.g. 3D fall protection plan with help of BIM viewer application.</i>
<i>3. Safety Notices Management</i>	<i>Recording notices at field digitally by mobile tools and putting an issue to someone's responsible and following corrective actions. Collecting, filtering and analysing up-to-date safety data is also possible, helping to decrease specific safety violations and develop safety management procedures.</i>
<i>4. TR Safety level measurement (weekly observed safety level at the site, a Finnish method)</i>	<i>Conducting mobile TR-safety level inspection and filing safety observations digitally, as well as calculating the weekly safety level rating automatically by the tool.</i>
<i>5. Other safety inspections</i>	<i>Ready-made digital checklists and forms, and filling out those digitally once while the inspection. Inspection forms may be for safety inspection process or checking cranes, for instance. Electronic time stamping registering visit entry and departure may also be included.</i>
<i>6. Browsing Safety and security regulations and guidelines, and accessing safety and health sites</i>	<i>Browsing OSHA-regulations, best practices, or fire protection standards at site. Browsing information on personal safety equipment requirements for a specific work</i>
<i>7. Getting information and help without delay in case of illness, accident, or other H&S related situation</i>	<i>E.g. iTriange: By entering the symptoms, one gets information about likely causes and a proposal for the treatment/action. By entering name of a drug/medicine, provides basic information and warnings related to the substance, and the location of the nearest first aid centre. (Professional Safety 2014)</i>
<i>8. Accessing chemical safety data</i>	<i>Information for chemical safety management by accessing chemicals database by mobile application. E.g. ChemAlert provides access to over 100 000 chemicals, and includes e.g. hazards classifications, recommended personal protective equipment and first aid information.</i>
<i>9. Photos and Panoramic photos (360 degrees)</i>	<i>Cameras can be used for documenting worksite conditions and helping safety personnel to identify safety hazards. Panoramic photos can be used for e.g. incident investigations and safety inspections, and created by help of specific applications such as DMD Panorama (Professional Safety 2014).</i>
<i>10. Measuring safety of the working conditions</i>	<i>Measuring angles of slopes to evaluate safety (e.g. Clinometer HD), or measuring sound level dB (e.g. SoundMeter) to determine whether a more precise measurement using more accurate device is necessary. Or measuring thermal conditions (e.g. OSHA Heat Safety Tool). (Professional Safety 2014).</i>
<i>11. H & S related calculations</i>	<i>E.g. iPad apps available for conventional safety management calculations (ready-made calculation formulas included in apps such as HSE Buddy).</i>

One of the first purposes of mobile tablet computers was to support more efficient access and viewing of 2D building designs and other construction documents at field, and at the same way, the traditional safety documents can be viewed digitally using tablets. However, designs and construction plans are used more and more by viewing BIM-based 3D models with tablets at field. As a natural step forward, BIM-based safety plans such as 3D fall protection plans can be viewed as part of construction documentation in the future. Figure 1 demonstrates how BIM-based safety plans could be viewed using e.g. iPad. Model viewing tools are already available for tablet computers, but BIM-based safety plans such as fall protection plans are not common in real construction projects yet. According to Krebs (2009), while BIM solutions were not designed with mobile applications in mind per se, mobilizing BIM applications significantly enhances not only their value but also the strategic value of mobile solutions to construction and engineering operations.



Figure 1: Structural 3D model including safety railing viewed in iPad using mobile application Tekla Field 3D.

3.3 Impact and benefits of the new technology

Summary of found and potential benefits of the new mobile technology are presented in table 3. Many of these listed safety related benefits may likewise be achieved in the quality assurance and management, for example, but information collected, recorded or analysed would just differ from the ones presented as examples in the context of safety management.

Table 3: Benefits of mobile technology in safety management.

<i>Benefit</i>	<i>Examples</i>
<i>1. Time savings, and at the individual level easier to deal with issues/work assignments on one's own schedule</i>	<i>Safety observations and notices are recorded and documented at once while inspection. Mobile application may also automate calculations related to safety auditing. Meeting minutes are made once during the meeting.</i>
<i>2. Improved productivity</i>	<i>Beside time savings, faster access to up-to-date project and safety related information improves productivity, as documents needed at field are carried along digitally in a mobile device or accessed on-line by web.</i>
<i>3. More systematic, transparent and traceable process</i>	<i>All concerned parties can see who and when created a safety notice or other record, who is responsible for correcting actions, how urgent it is to correct the issue, and a notification of fulfilling the task.</i>
<i>4. Better information quality</i>	<i>Easier to manage the project information timeliness with help of a cloud-based system. Easier access to e.g. safety regulations to consider safety more carefully in a specific construction phase or work task. More accurate documentation of safety issues, since information structure/content is standardized by digital forms in app and e.g. photos can be attached to any issue.</i>
<i>5. Faster resolution of problems and faster access to first aid information</i>	<i>Faster access to safety information and guidelines e.g. in a case of injury. After an accident, the history data of issue management may help find the reasons at the background of it. Additionally, faster resolution of any occurring issue in a project decreases also safety hazards.</i>
<i>6. Automated reporting, filtering and summary concerning site status</i>	<i>A list can be produced e.g. of all safety notices recorded at one building site, or of all which one specific firm is responsible for. Summary of the most common safety violence types at the specific construction site can also be automatically filtered from a cloud-based database, to tell which issues should be addressed and corrected.</i>

The most obvious benefits are 1) *time saving in resource use* and 2) *improved productivity*. According to a survey conducted by VDC Research, investments in mobile and wireless solutions provide real and measurable benefits, improvements in worker productivity being 30.1% (Krebs 2009). For example, in case of safety inspection, there isn't need to make written notes first and then make documenting as an additional task after getting to the office. Experience shows, that this speeds up the safety inspection process significantly (Lemmetty 2013).

In a tablet computer pilot construction project described by Löfgren (2007), the users experienced improvements in their own personal productivity when equipped with updated project information on tablet computers. Also to solve arisen on-site problems and critical construction issues there is a need for quick access to necessary information. Previously production management personnel used to run back and forth between the construction site and their computers inside the site office, leading to inefficient use of managerial resources. With issues resolved quickly and returned to the field accurately, field staff was able to continue to

work unhindered. Additionally, meeting notes can be taken directly with the electronic pen on the tablet computer. Using the built-in tablet computer text recognition tool, the notes can be translated into an ordinary data text document when the meeting is over, which directly can be distributed via e-mail to project participants. (Löfgren 2007)

At site level, mobile cloud-based tools enable *more systematic, transparent and traceable safety issue management process*. Various players of the building project get better opportunity to inform others about their safety concerns, and all parties concerned get notification about the issue, as well as how and when it was solved. E.g. various subcontractors get better opportunity to plan their own tasks, since they will be notified if problems affecting their work occur at site, as well as when the issue is solved. At the end of the project there are less unclear issues.

Better information quality: Distribution speed, information quality and understanding of production issues communicated to involved actors can be enhanced (Löfgren 2007). Mobile tools provides faster creation of records once it is identified at field, and understanding of occurred issues is easier if text descriptions are supplemented with attached photos, for instance. Also information quality is better in manner of timeliness: If compared to the traditional way of carrying along blueprints, there is faster access to safety related up-to-date information, since drawings, 3D models and other documents can be updated to the mobile device for viewing whenever, provided that there is just Internet connection. Site staff does not need to go to view their computers inside the site office to get the information needed. In the other words, relevant safety information can be brought closer to the production event, where it can genuinely affect occupational site safety.

Faster resolution of problems and faster access to first aid information: In case of injury or accident, various mobile applications provide faster access to first aid information and help making documentation for later analyses. In the future, mobile information delivery provides possibility to completely new kind of information contents as well, since information is available in the web and can be combined automatically with the information, which origin is in totally different place or different parties of a building project.

Automated reporting, filtering and summary concerning site status: Beside direct benefits, the indirect benefits of mobile tools may actually be even more significant. If information on e.g. safety issues is systematically recorded, resulting project-specific database makes it possibility to automatically summarize, filter and analyse current safety hazards at site, as well as identify development needs in the longer term. Additionally, based on occurred safety issues on site, automated alarms become possible, such as issues to take care of today, issues to take care of in a coming week, and actions that are overdue. Such features are included e.g. in Trimble's "ProjectSight" application, when PC and web-browser is used as interface to project data recorded at site. The "Project dashboard" shows the summary of realized safety on the specific site, and by help of this automated safety issue analyses, the site manager can monitor what kind of safety violations have occurred most. Other automated features include possibility to filter safety notices in various ways such as "All" or "Pending me", for instance.

As a result of cultural differences in the traditional construction procedures, there are differences in the most appropriate or useful use cases of mobile tools in various countries. Löfgren (2007) describes that while supervising teams in the U.S. appreciated the tablet computer in their first pilots as a tool for handling and updating digital drawings, in Sweden that had a very limited application area due to a completely different way of administrating the blueprint update process. The tablet computer project in Sweden was leaning more towards enabling more effective on-site administration of construction activities through mobile on-demand access to existing business information systems and construction project administration tools to e.g. fill out field work report forms online. Cultural differences make also localization of the mobile applications necessary, since the interface of the tools should be as easy to use as possible and guide the user to common systematic workflows including e.g. using a relevant record type for a specific issue and filling the related information in a same way each time. These requirements can't be fulfilled, if terms are in foreign language and thus not clear to the users.

4. Discussion

Exploitation and effective use of mobile applications require features which are appropriate for construction and safety management procedures at field. As a result of national differences in traditional processes, this will most likely lead to localizations of the most promising tools. On the other hand, it's possible, that as a result of implementation of new genius mobile tools, the more effective working procedures are adopted and spread around the world decreasing cultural differences in construction processes. However, the traditional processes should not be digitalized as such, but at the same time with the mobilization it should be considered, if the process itself could be simplified as is the target in the Lean construction. Current web-based application stores provide very efficient selling and delivery network of mobile applications already now, but the internationalization of workflows would further increase their markets, and speed up development of the digitalization in construction industry on the whole.

In case of construction site's mobilization, it's important to take into consideration also risks related to mobile devices in general. Mobile devices and digitalization rise up concern about data security and reliability of mobile information. Further research concerning risk management of mobile applications at construction sites is definitely needed. It is also clear that mobile device itself can cause near miss situations or accidents by occupying personnel's focus in a dangerous working environment.

The Internet of Things (IoT) development of computer technology will bring whole new kind of possibilities to combine information for improving occupational site safety management. For example, Jiang et al (2013), identifies possibility to add new monitoring devices such as smoke sensor to the web-based safety management system. IoT development enables variety of data to be analysed and reported. By utilizing IoT and computer technology for example individual wellbeing of site staff can be monitored and analysed in order to support occupational safety and health.

5. Conclusions

Utilization of mobile tools is increasing rapidly on construction sites, and so do availability of mobile applications and cloud-based solutions meant for construction industry. Found mobile tools including some kind of safety related features were categorized in this research into 4 types: *Construction project management applications including safety related tools*, *Safety auditing or safety level inspection / measurement/rating applications*, *Applications for a single specific safety related purpose*, and *Applications meant for a specific construction phase or work*. These has been tested for various purposes in different countries, and especially mobilization of BIM and e.g. issue management seems significantly increase the value of mobile devices in the future.

The most obvious benefits resulting from mobile tools are time savings in resource use, and other productivity improvements at personal, site or company level. Achievable benefits include also more systematic, transparent and traceable issue management process, for instance, and better information quality e.g. in terms of timeliness. Faster resolution of problems and access to e.g. first aid information may become a lifesaver for an individual. However, the indirect benefits of automated reporting, filtering and summary concerning site status may be even more significant from the view point of improving site safety. If e.g. safety issues are systematically recorded, resulting project-specific database makes it possible to automatically analyse current safety hazards at site, as well as identify development needs in the long term. Additionally, based on occurred safety issues on site, automated alarms become possible, such as issues to take care of today, leading to more effective hazard prevention proactively. When sub-contractors also begin to use more tablet computers and the mobile applications, the general contractors and the building projects as a whole start to gain more benefits from these tools in terms of efficiency. That's because the same information doesn't need to be provided in many different ways for the various project parties anymore. Mobilizing BIM own remarkable potential to enhance their value, but also the value of mobile solutions to construction and engineering operations.

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Visualization of building models and sensor data using open 3D platforms

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Abstract

Modern facilities management in digital systems requires user-friendly tools for visualization and decision making, and improved data. To help achieve this, 3D models can operate as a platform for integrating sensor data and other documentation for a building. If 3D models are not readily available for a specific building, measuring methods can be applied. In this article, a prototype of a building model with a sensor data visualization system is presented using an open source 3D platform. The prototype is utilized to visualize 3D models produced by terrestrial laser scanning, thermal camera images, and sensor data. Several development directions are identified for such systems.

Keywords: indoor air quality, building model, laser scanning, maintenance, visualization

1. Introduction

In building information modeling (BIM), the information representing different disciplines in the field of construction (architecture, engineering, etc.) are integrated into a three dimensional (3D) digital model. With the help of BIM, it is possible to detect collisions and conflicts in an early stage of design (Azhar, 2011) and, for example, improve scheduling in the construction phase (Tulke et al., 2008).

However, the construction and planning only represent a small fragment of the total life cycle of a building. Contemporary buildings contain a multitude of different technical systems that need to be managed during the operational life of the building. The increasing complexity of the buildings is putting pressure on the traditional methods of facilities management, as stated by Ahn and Cha (2014). Several authors have suggested that a BIM-based solution has to be applied for facilities management (Becerik-Gerber et al., 2012; Ahn and Cha, 2014). By aggregating facilities management data into a BIM model, the data management issues caused by missing or non-synchronous documentation can be solved (Ahn and Cha, 2014).

Sick building syndrome exists in Finnish public buildings (Audit Committee of the Parliament of Finland, 2013), as in so many other countries globally. Complicated building structures and growing needs for better indoor air quality increase the need to monitor, adjust, and supervise building parameters properly and illustrate data visually in a compact form (Hietsalo et al., 2014). More sensors and wireless networks are needed to fulfill those requirements. In particular, there is a demand for better control of relative humidity (RH), dew point calculations, CO₂ sensors and total volatile organic compound (TVOC) sensors to assure healthy indoor air. The absolute amount of water vapor in indoor air can be determined by combining data on RH and temperature. The difference between the amount of water vapor in indoor and outdoor air is a good indicator of the efficiency of building ventilation. In a similar manner, the pressure difference between the building interior and exterior is a good indicator of a properly operating ventilation system: If the ventilation system is correctly adjusted, the pressure difference should be low to prevent any unintentional air flows, and so forth. For monitoring the building envelope, continuous measuring is important, as the amount of moisture can, for example, vary significantly during a single day. As a result, one time measurements become unreliable. Sensors can also be integrated into building structures. By measuring the moisture of building structures, it is possible to monitor, for instance, the drying of a concrete structure after repair work. By combining the data from indoor condition measurements and structural measurements, there is the potential to estimate the risk of mold growth.

If BIM-based facilities management methods are to be applied in these cases, measuring and modeling becomes essential. On this point, Tang et al. (2010) provide an overview of the automated as-built BIM reconstruction problem and some of the partial solutions. This reconstruction can be performed manually, by viewing a point cloud in a computer-aided design (CAD) suite and building the model (Mill et al., 2013). A similar approach can be found in building modeling using terrestrial laser scanning (TLS), as presented by Arayici et al. (2007)

for example. In most cases, however, the modeling is too laborious. While the project may be carried out without the comprehensive model, many of the benefits of BIM are not attained.

For both manual and semi-automatic BIM reconstruction, laser scanning can be used as a measuring method. In measuring the built environment, it is usually applied as TLS, with the instrument being mounted on a tripod. In laser scanning, the laser pulse travel time or phase difference is used to calculate distances relative to the scanner position. By combining data from the scanning angle and impact of atmospheric reflection caused to the speed of light on the time data, 3-dimensional locations of the scanned points can be identified. If the scanner positions are known, several scans can be combined to create a larger point cloud of the built and natural environment (Virtanen et al., 2014c; Lehtola et al., 2014; Kankare et al., 2013). The high point density and fast acquisition speed make laser scanning an efficient method for documenting complex building surfaces (Virtanen et al., 2015), rapid prototyping (Virtanen et al., 2014a), and detecting structural deformations in buildings with great accuracy (Virtanen et al., 2014b). On this point, Chee Wei et al. (2010) present the workflow for utilizing terrestrial laser scanning from a cultural heritage documentation project. The documentation of the chosen artifact is conducted with a laser scanner. Scanning targets are used for both registering the scans and geo-referencing the project. In addition, digital images are taken with the integrated camera system of the scanner to obtain RGB values for the scanned points (Chee Wei et al., 2010).

Mobile laser scanning (MLS) has generated a large amount of interest for measuring and modeling urban environments. In particular, it is suited for measuring in outdoor environments, producing models of e.g. building facades. Typically, MLS systems are mounted on regular cars, but there have been implementations of MLS on a cart or an all-terrain vehicle (ATV). One such example of a MLS system is the ROAMER system, developed at the Finnish Geodetic Institute (Kukko et al., 2007). The essential components of a MLS system are a laser scanner, GPS receiver, inertial measuring unit (IMU), and data recording system. The GPS and IMU are jointly used for the accurate localization of the MLS systems (Kukko et al., 2007).

In addition to laser scanning, image-based measuring methods (digital photogrammetry) can be applied for precise 3D documentation (Virtanen et al., 2012; Kurkela et al., 2012). Different types of images (panoramic image mosaics, image databases, sensor images, and multispectral photographs) are employed to produce information from the environment.

Another significant source of data concerning buildings are sensors. Several types of sensors can be installed in a building to measure a variety of parameters (such as CO₂, temperature, and amount of light). In this field, one of the research directions is wireless sensor networks (WNS) that can be applied in construction and building maintenance. As the “health” of a building is dependent on a large group of factors, different sensors are required to follow a group of parameters. To produce comprehensive data, these sensors have to be scattered across all parts of the building and also installed inside the structures. WNS can help reduce the amount of cabling needed for such installations and thus help reduce costs. When using sensor data for decision making in construction, data visualization becomes a central task. A large amount of data must be presented, preferably dynamically, so that it can be seen in near real time

(Hammoudeh et al., 2015). If this data is to be utilized in decision making with the 3D building models, they have to be visualized together. This both simplifies the interpretation of data and enables the detection of correlations (Motamedi et al., 2014). It is possible to identify temporal correlations from the sensor data, e.g. the impact of microbiological activity on the CO₂ concentration. It is also possible to search for long term trends and thus try to identify potential problems before they emerge and become acute. In current planning and maintenance systems, buildings are mostly studied as individual entities. This reduces the overall efficiency that could be reached by looking at interactions not only within a single building but between buildings. Networking the buildings and analyzing their data, energy, and resource flows is the key to unlocking the full potential of these networked, smart buildings. The resulting Internet of Buildings can share resources and thus optimize the use of energy and services, to maximize the efficiency when using renewable natural resources. For buildings in this networked ecosystem, new business models can be created, thus improving the conditions of the building owner as both a consumer and provider of services (Lukin, 2015).

The four mentioned aspects are combined in the future digital models used for building upkeep and maintenance (Figure 1). Firstly, a digital 3D model operates as a platform for information and forms the starting point for all building maintenance activities. Secondly, all data concerning the building is aggregated on top of this model, the individual data sets being bound to respective model components. Thirdly, the sensor data from the building is integrated into the same model and visualized. And finally, the model has to operate in a networked system, enabling the integration of several buildings or other online resources. In addition, if the proposed solution is to be applied to the current building stock, for which no BIMs exist, the starting data for the model has to be generated using the existing 3D measuring techniques.

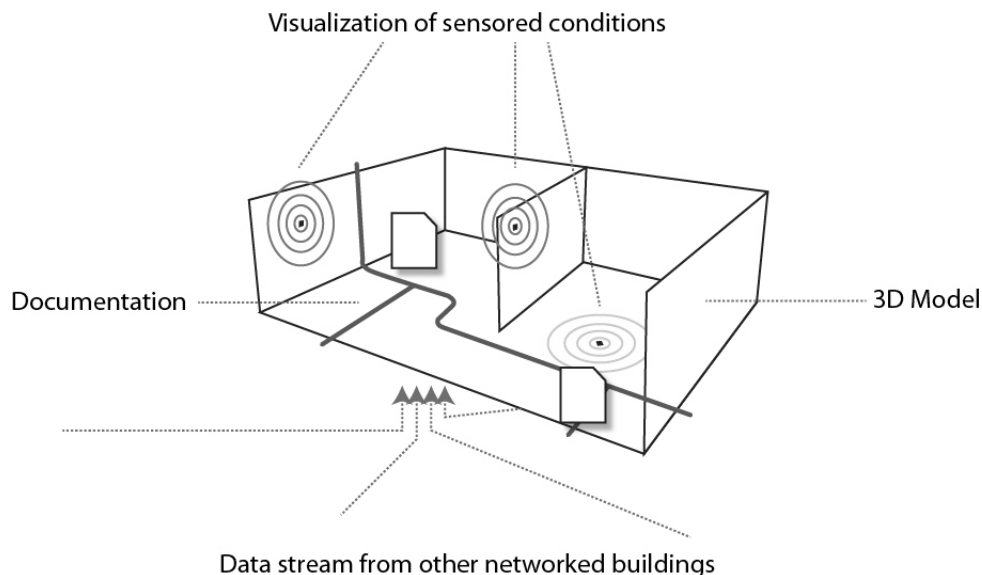


Figure 1: The aspects of future digital models used for building upkeep and maintenance

Thus, this paper presents a 3D visualization method as a tool for analyzing and viewing 3D building models with additional sensor data. 3D measuring techniques are utilized to produce models that depict the building as it is in use. The visualization results focus on indoor air quality measurements. This solution will provide information for monitoring the status of the indoor environment of the building. The goal of the system is to improve indoor air quality and reduce the cost of unnecessary renovations.

To proof the system, various sensor data will be combined with a 3D model. Data from imaging sensors, such as a thermal camera, and individual sensors, such as temperature, moisture, and carbon dioxide, is used as the test data set. Moreover, an open 3D application development platform is utilized to visualize the building models. A user interface is then developed to facilitate the study of time series. The resulting model can then be used to study the state of the building and its indoor air quality. Based on this prototype, the aim is to outline future development directions. To take the whole operational life of the building into account, models have to include, as much as possible, all information concerning the use and upkeep of a building.

2. Materials and methods

2.1 Measuring methods for indoor environments

The open source 3D Internet application platform was used to host the building models created and operate the developed applications. The resulting virtual scene is defined in a TXML file, following the XML syntax. Each object in the scene is defined, with the object geometry being stored in an external file, accessible over an http connection (realXtend, 2015; Alatalo, 2011).

To obtain indoor measurement data from one of the test sites, the test utilized the Faro Focus 3D terrestrial laser scanner and Matterport Pro 3D Camera. Faro Focus 3D is a conventional TLS instrument with an integrated camera designed to obtain texture images that can be used to colorize the point cloud in later processing (Faro, 2015). The distance measurement accuracy of the instrument is ± 2 mm at a distance of 25 m (Chow et al., 2012). Faro Scene software was utilized to process and co-register the TLS scans. Matterport is a commercial solution for measuring indoor environments based on depth camera technology (Matterport, 2015). The device is used to acquire a set of panoramic depth images from the environment, with each image covering a full 360° field of view. The 3D reconstruction process is performed automatically with cloud computing. After the user has uploaded the measured data, an optimized alignment of the 3D captures is solved, and a textured mesh model created (Bell et al., 2013).

Four different model reconstruction methods were employed: three dimensional models were created from the TLS point cloud using AutoCAD 2016 and Geomagic Design X. In addition, the automated generation of a mesh model was performed from the TLS point cloud by using Geomagic Studio 11. For the Matterport data, the automatic online service of Matterport was

used to obtain the mesh models. After the modeling, game engine compatible models were created in Blender for use as game engine equivalents for the visualization.

2.2 Sensor networks

Data from the 720 indoor air quality measuring system (720, 2015) was employed in the experiment. The sensors were installed in two rooms of the test building. The data consisted of the hourly averages of the CO₂ concentration, relative humidity, temperature, and TVOC concentration. In total, the time series contained some 1030 readings, spanning a time period of 43 days. A small application was also written on the platform to visualize the data.

2.3 Online 3D building maintenance model

To assemble an online 3D representation of all data available from the building, a data model was utilized that divided the data into both individual spaces and data types. In the resulting model, each single entity of data (e.g. a Flir image or a 3D indoor model) was given two identifiers, a room code and a data type. The data types are provided in Table 1. The full set of metadata defined for objects is given in Table 2.

Table 1: Data types

<i>Name</i>	<i>Description</i>
<i>2D CAD</i>	<i>Two dimensional CAD drawing</i>
<i>3D CAD</i>	<i>Three dimensional CAD model</i>
<i>Mesh</i>	<i>Triangulated 3D mesh</i>
<i>FLIR</i>	<i>Thermal image</i>
<i>Picture</i>	<i>Image</i>
<i>Point cloud</i>	<i>Three dimensional point cloud</i>
<i>Document</i>	<i>Text document</i>
<i>Other</i>	<i>Other than above types</i>

Table 2: Object metadata

<i>Attribute</i>	<i>Description</i>
<i>Data type</i>	<i>Data type (listed in Table 1.)</i>
<i>Data source</i>	<i>Description of source (e.g. measuring instrument used)</i>
<i>Room identifier</i>	<i>Unique identifier of room in building (e.g. room number)</i>
<i>Building identifier</i>	<i>Identifier of building (e.g. address or name)</i>
<i>URL</i>	<i>Path of the full data (e.g. on intranet server)</i>
<i>Additional information</i>	<i>Any additional descriptions of data set</i>

As the chosen game engine-based system was unable to represent all object types, game engine equivalents were created for all objects. These equivalents were created by producing mesh models of the reduced polygon counts for all 3D objects and textured planes for the 2D objects. After this, the location of the actual data was input to the metadata of the object in TXML. Thereafter, an application was developed that allows the user to select individual spaces of the building, to choose the displayed objects according to data types, and to study the values of the sensor time series.

3. Results

By using the methods described, a virtual scene depicting two rooms of the test building was created. The orientation of these data sets was resolved manually, and the metadata was input for the objects. The resulting scene was hosted using a realXtend server. In the tests, a local machine was used to run the server and access the scene. In the scene, different measuring data sets are displayed in the same virtual 3D space.

In the scene, a user can filter the displayed object according to the data structure described, fetching data sets of a certain class from each room individually. The counts of objects available on the server for each type are displayed. In addition, there are tools to hide all data sets or isolate an individual data set for study. The values obtained by the 720 sensors are displayed next to each room. To enable functionality, a user interface is provided for jumping backwards and forwards in the time series. Accordingly, Figure 2 illustrates the system displaying Matterport mesh models for both rooms, the sensor data for both rooms, and a set of thermal images for the other room. As shown, the user can move freely in the virtual 3D space. Figure 3 also demonstrates a preview of a thermal image being shown inside a mesh model.

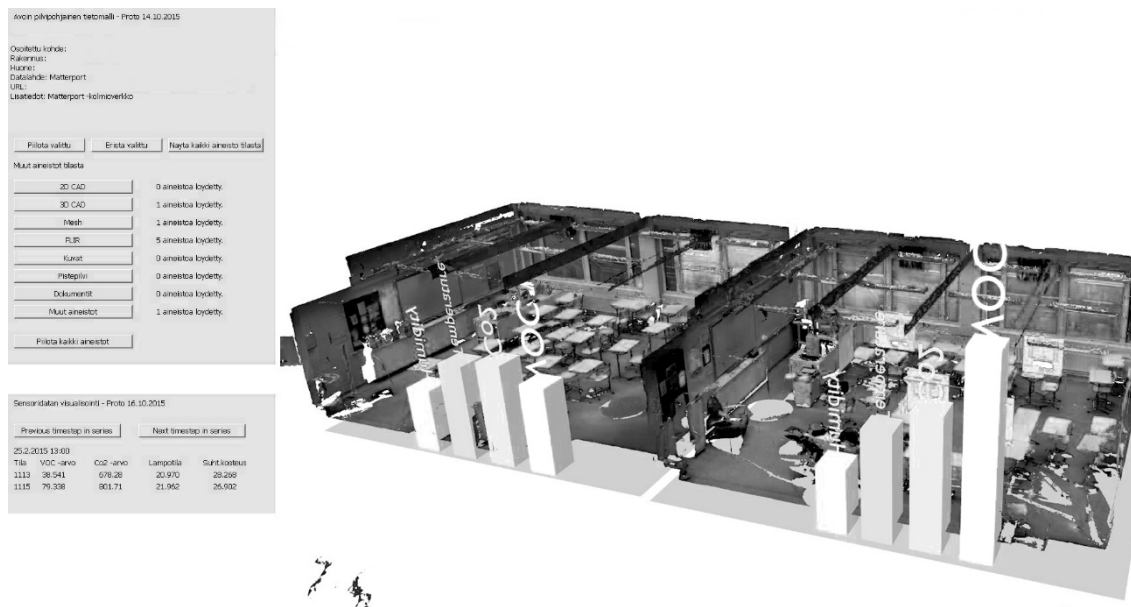


Figure 2: System in use, displaying some data for both rooms



Figure 3: Studying an individual thermal image in the data set

4. Discussion

The presented setup is able to display objects of different types in a virtual 3D space and also sort them according to the metadata. There are a number of advantages that can be found in the proposed system. Firstly, the concept of using game engine equivalents is essential for the development of computationally light applications that operate over the Internet. As there are already browser-based systems that utilize the same architecture (Meshmoon, 2015), the possibility of developing fully browser-based tools remains. A simplified, game engine-optimized model can, in these systems, be used to depict a larger, more complex model. In this way, the user can preview the model relatively quickly and then download the full model later, using the existing tools of the industry (e.g. point cloud processing software or full-featured CAD) to study and process the actual model. Secondly, the usage of game engine equivalents enables the utilization of existing game engines for application development. This is already being conducted in several cases where, for example, Unity (Unity, 2015) is used to display building models. Thirdly, by leveraging the typical features of game engines, the system is able to represent both 2D and 3D data along with dynamic and static data in the same environment.

However, as the system is still a very early prototype, it has a number of apparent shortcomings. Firstly, the amount of automation in the content production is very low. Content building methods more familiar to the game development industry than construction have to be applied for making game engine equivalents of the 3D models. As such, the system is unable to directly support model formats commonly used in construction (e.g. DWG or IFC). Secondly, the

orientation of the data sets with respect to each other has to be solved manually, if the data sets are in a different coordinate system. For example, Matterport mesh models had to be manually moved to match the coordinate system of the TLS campaign. Finally, there are no automated tools for adding new objects to the scene; the user must use the tools offered by the platform. These shortcomings render the current system unfeasible for immediate wider adaption.

Comparing the presented prototype to the aspects of future digital models employed for building upkeep and maintenance as presented in the introduction, it is possible to identify several development directions for the system. The future development roadmap is summarized in Table 3. The main development directions are the increase in the applicability of the system to large models, the inclusion of the entire building life cycle, and finally the support for sensor networks. With these development directions, the integration of geometric, sensor, and maintenance data becomes an important research focus.

Table 3: Future development directions

	<i>Large, detailed models</i>	<i>Building Life Cycle</i>	<i>Network of smart buildings</i>
<i>Application</i>	<i>Renovation Existing building stock Modeling of large complexes</i>	<i>Life cycle simulation Building maintenance Comparison with as-built data, identification of deviations</i>	<i>Multi-building systems Prediction models, alerts</i>
<i>Data integration</i>	<i>Integration of geometric, sensor, and planning data</i>		
<i>Platform development</i>	<i>Support for large data sets Segmentation, Optimization</i>	<i>IFC models Integration to planning systems Model change detection & updating</i>	<i>Interfaces Data visualization</i>
<i>Data sources</i>	<i>Big Data Open Data Measuring methods</i>	<i>Facilities management Building planning</i>	<i>Internet of Buildings Dense sensor networks</i>

5. Conclusions

Smart management of existing buildings requires new tools that integrate data from several sources and enable the study of networks of buildings. Based on the literature, the four features of future models used for building upkeep and maintenance were identified: the use of a virtual model as a starting point for operations, the aggregation of data on top of the model, the integration of sensor data to the model, and the building of an Internet technology-based networked system for maintaining and accessing the model.

In the presented experiment, data from 3D measuring techniques and imaging was used to build a prototype of such a model, consisting of two rooms in a larger facility. To achieve this, virtual world technology was used as a platform for the prototype. A simple application was then developed to facilitate the study of the models and other data. As such, the system was able to visualize the data. However, the low degree of automation in constructing the model prevents the immediate adoption of the proposed system.

Future development directions include the increase of automation in the content building of the presented system, the utilization of browser-based technologies, and the pilot use of the system to better identify development needs. With measuring techniques such as MLS, a 3D time series can be created for identifying geometric changes in the environment. 3D application platforms based on client-server architecture are well-suited for prototyping these models and visualizing data from the various sensors together with the 3D models.

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BIM-supported Life Cycle Analysis: A Case Study

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Abstract

Building Information Modelling (BIM) as emerging technology, bears promise to enhance the process-integration in the AEC industry and thereby enable life-cycle optimization of built environment. BIM model should serve as a joint knowledge database for the interdisciplinary planning team, offering thereby significant potentials for analysis and optimization of the overall energy- and resources efficiency already in the early design stages; however these potentials remain largely still unexplored.

This paper explores the potentials of BIM as support tool for life-cycle assessment (LCA) and structural analysis in the early design stages on a case study of a timber-structure housing block. The timber-based structure and wooden façade promise higher eco-efficiency in terms of CO₂ saving, however in order to support the decision making process towards such more sustainable construction, a decision making process towards optimisation of the structure based on life cycle and structural analysis is needed in the design stage.

Upon initial creation of BIM architectural model in Archicad, we carried out a comparative life cycle analysis study for assessment of the environmental impacts of the construction materials. The automated process using BuildingOne Tools with direct access to BIM model linking the eco-indicators to the specific materials and building elements and assessing overall eco-efficiency was compared to the “manual” data handling and LCA-calculation using Exel Software.

The varying needs concerning the Level of Development (Level of Development is the degree to which the element’s geometry and attached information has been thought through) and semantical differences in the modelling procedures of the part-taking disciplines (architecture and engineering) were identified as main reasons for the defects of the building models.

Further on, lack of standards for parameterization of intelligent, digital building products in terms of LCA, that would unify property definitions used by eco-inventories or environmental product footprints and BIM libraries represents difficulty for the automation of life-cycle assessment. In order to improve BIM based life-cycle analysis, not only interoperability of the software has to be improved, as well as re-design of the design process and enhancement of individual capabilities.

Keywords: BIM, LCA, Optimization, Structural Analysis

1. Introduction

The achievement of sustainable built environment is based on energy and resources efficient construction. Thereby the design stage is of crucial importance (Azhar et al, 2011), since the impact of decisions made in this stage has the largest impact on the life cycle performance, at a very low cost. Simultaneously, the early design stage is critical in terms of decision-making and knowledge management, since the level of design-information is low, the design-knowledge is mostly implicit and difficult to grasp or communicate, which makes decision-making process extremely difficult. Simple, easy to handle tools for the prediction of future building performance that would enhance the decision support in the early design-stages are lacking. Thereby, design-oriented methods for prediction, simulation and optimization enabling decision making support in the choice of most balanced solution in terms of environmental performance and resources efficiency are needed.

Buildings run through various life cycle stages – design, construction and operation, where in each phase data is exchanged among team members, in order to document the current state of the building. The information exchange occurs on several levels – face to face communication, analogue, drawings or planning documents, digital or CAD planning documents - along proprietary or open data standards (interfaces) in various software platforms. There by knowledge transfer and loss represents the greatest challenge, partly due to the fragmented nature of AEC industry and silo-thinking, and partly to the lack of efficient means and methods for data exchange and transfer.

Building Information Modelling (BIM) as emerging technology, bears promise to enhance the process-integration in the AEC industry and thereby enable life-cycle optimization of the built environment (Fellows and Liu 2010). BIM, as defined by National Building Information Model Standard Project Committee (buildingSmart, 2015) is a digital representation of physical and functional characteristics of a facility. Various 3D, intelligent, data-rich building information models can be exchanged within the project team and ideally throughout the life cycle of a facility (Smith and Tardif, 2009). BIM acts thereby as an integrated platform for team members to share and exchange project information in the phases of design, construction and operation (Eastmann et al, 2011) thus serving as planning documentation as well as for data management; supporting decision-making process. In order to enable smooth data exchange and transfer without data-losses, open standards and interfaces are needed, such as IFC - Industry Foundation Classes (buildingSmart, 2015).

Further on, BIM as a parametric, data-rich model enables follow up analysis such as structural analysis, thermal or lightning simulation, assessment of environmental and economic impacts through life cycle assessment, life cycle costing etc. (Diao et al, 2011). However, in order to employ such follow up analysis in the early design stages, and make it a standardised procedure within design process as decision support instrument, ease of use, user-friendliness and high level of automation in data exchange between various tools is needed.

Using a case study of timber-structure housing block, we will explore the potentials of BIM as knowledge platform for life cycle optimization in the early design stages. Thereby we will apply the BIM modelling methods for the creation of architectural model, and carry out follow up analysis involving life cycle assessment and structural analysis, thus enabling design-optimization in the early design-stages. Thereby we will evaluate the employed software tools as well as the work-flows, and outline the potentials and deficits.

2. Related Work

Potentials of BIM-use for life cycle analysis in the design stage has been of increasing interest in the research community. Especially interesting is so called BIM to BEM approach – transfer of building information models to building energy modelling for follow up thermal simulation. Model exchange in this area has been especially troublesome, since commercial BEM software such as Energy Plus or similar do not support IFC interface, but a proprietary gbXML interface, which makes the transfer particularly troublesome. Researchers such as O’Donnell et al (2014) propose a workflow for BIM to BEM based on IFC interface, proposing so called BIM Model View Interface, allowing semi-automated model exchange. Schlueter and Theselling (2009) develop a proprietary tool for energy performance analysis in design stage for Autodesk Revit software platform. Azhar et al. (2013) undertake a thorough analysis of BIM fitness for sustainability assessment using LEED rating analysis, establishing a procedural framework between the environmental analysis that can be carried out using BIM model, and LEED credit requirements, however they conclude that the automation of the workflow is not possible, due to the lack of LEED features integrated in the software.

3. Research Design

Upon initial creation of BIM architectural model in Archicad 19 BIM-Software platform, we carried out a comparative study of life cycle assessment of the environmental impacts of the construction materials. The semi-automated process using BuildingOne Database with direct access to BIM model linking the parameters of eco-indicators to the specific materials and building elements and assessing of overall eco-efficiency was compared to the “manual” data- and parameter handling and LCA-calculation using MS Excel. The obstacles in the semi-automated process will be identified as well as the difficulties in the manual process.

In the further step the primary loadbearing structure from the architectural model was transferred to the structural analysis software package via .ifc interface, in order to optimise the load bearing structure. Thereby data-transfer was tested in terms of data-losses and model coherence from architectural to structural model.

The Case Study consists of following steps:

1. Step: Creation of BIM model for a specific case – exploration of densification potentials of supermarket sites

2. Step: BIM for LCA – comparative study of a) semi-automated LCA using BuildingOne Database and b) manual LCA using Excel sheet (not automated)
3. Step: Work flow analysis of Transfer of BIM model to Structural Analysis via IFC interface

3.1 Methods and Tools

For the creation of Architectural Model, Archicad 19 was used, as certified software for both .ifc import and export. The model was created in the Level of Development 300 (BIMforum, 2013). Thereby the building elements are defined as load bearing and not-loadbearing (walls, columns and slabs). The building elements are defined as multilayer-building elements, in order to be allow latter parameterization of material and elements through parameters such as area, eco-indicators, etc. of the building elements, needed for the LCA.

Life Cycle Analysis was carried out applying the IBO (Austrian Building and Ecology Institute) OI3 Index (2013) methodology. The OI3 Index is generally based on assessment three of indicators – Global Warming Potential - GWP, Primary Energy Indicator- PEI and Acidification Potential (AP) for the construction-materials of a building. The single materials are bundled into the multi-layer building elements (e.g. exterior wall). The methodology finally proposes an assessment of a single, synthetic indicator as weighted sum of the three sub-indicators, which is benchmarked with the proposed grading system, finally obtaining a level of certification within the IBO-Index system. The methodology proposes several scenarios regarding (spatial) system limits, ranging from inclusion of building envelop only, to inclusion of complete building systems. We have opted for so called BG1 scenario, where complete thermal building envelope and interior slabs only are included in the assessment (interior walls excluded). The data-base used for the attribution of eco-indicators is also IBO Catalogue of Elements.

BuildingOne (2015) is a database originally created for the management of room-data sheets, enabling quantity survey, cost calculation and estimation. It offers bi-directional data exchange between the database and BIM software, such as Achicad 19 or Revit, and the data synchronisation. Through compilation of own queries customised calculation can be carried out, and exported into MS Office Platform (Excel). Since quantities (parameters) can be user-defined, the follow up calculation it terms of LCA can be carried out using customised queries and scripts.

Structural Analysis of primary loadbearing structure (timber) is carried out using Dlubal RFEM software, for the Finite Elements Analysis. RFEM provides deformations, internal and support forces as well as soil contact stresses. Add-on modules facilitate the data input by creating structures as well as connections automatically and perform further analyses and designs. Since there is no direct, proprietary interface between Archicad and Dlubal RFEM; the data is transferred using IFC interface. The model in Archicad is crated in such way, that building elements are differentiated in load bearing and not-loadbearing elements, only loadbearing elements are transferred in the Structural Analysis Software, for the simplification of the analysis-process.

4. Case Study

4.1 Architectural Model

In the year 2025 a population of almost two million people is being expected in the city of Vienna, which means that about 11.000 new apartments will be needed each year. As building land reserves are rapidly decreasing, new concepts for supporting densification are required. Numerous supermarkets within highly urbanized neighborhoods and their related vast parking spaces represent huge building land consumers, promoting urban sprawl as a result.

In this case study, a densification-concept is developed through proposing a timber housing block on the parcel and above one of such supermarkets in Vienna, in order to improve the overall ecological efficiency of the site (expressed in kg of CO₂/Occupant). Thereby the design is carried out using BIM planning method, exploring the potentials of BIM for follow up analysis such as life cycle assessment for compilation of eco-efficiency and structural analysis for feasibility and optimization of the load-bearing system.

The model is as mentioned in the chapter 3.1 modelled in Archicad 19 BIM software (Figure 1), as open-platform BIM software, enabling data-transfer using .ifc interface (open standard). Projects are temporary constructs, characterized through high level of uncertainty, e.g. unknown planners and software-constellations. In such setting, open interfaces are needed for smooth data transfer and project progress.

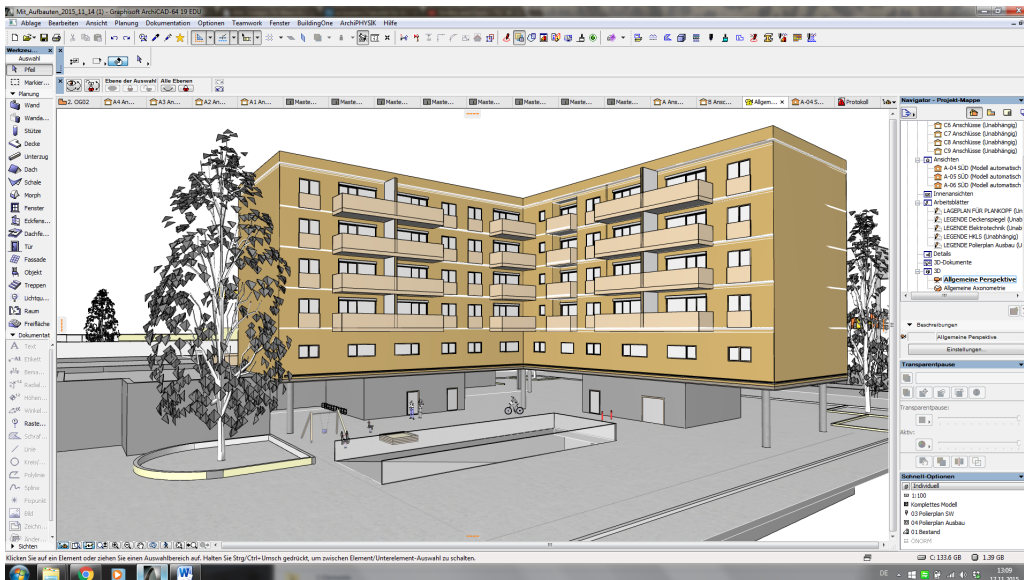


Figure 1: Architectural Model

All of the building elements regarding the building envelope (outer façade walls, roof, bottom slab) as well as the interior slabs were modelled as multi-layer elements (Figure 2), in order to be able to carry out the latter LCA according to OI3 Index, with system limit BG1.

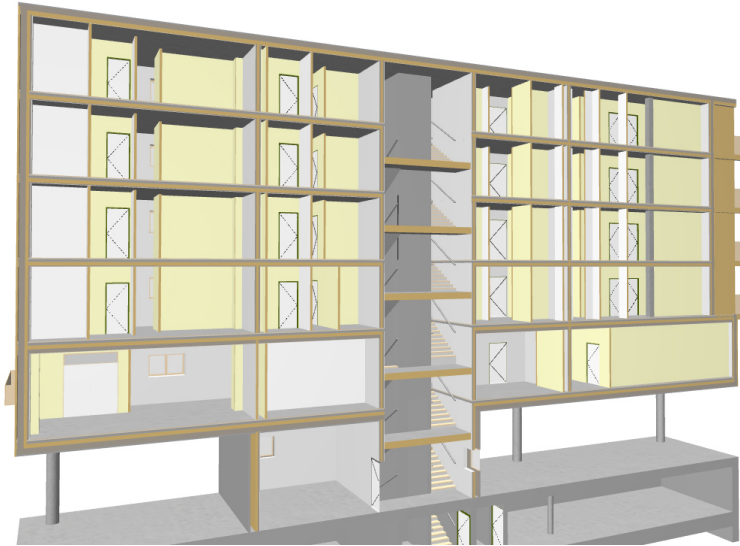


Figure 2: LOD – Multi-Layer Elements

Since eco-indicator data is difficult to obtain for specific materials, as first step the layers were defined in descriptively in .xls using the eco-indicators. Only after this the multi-layer elements were modelled and parameterised in Archicad – Model (Figure 3).

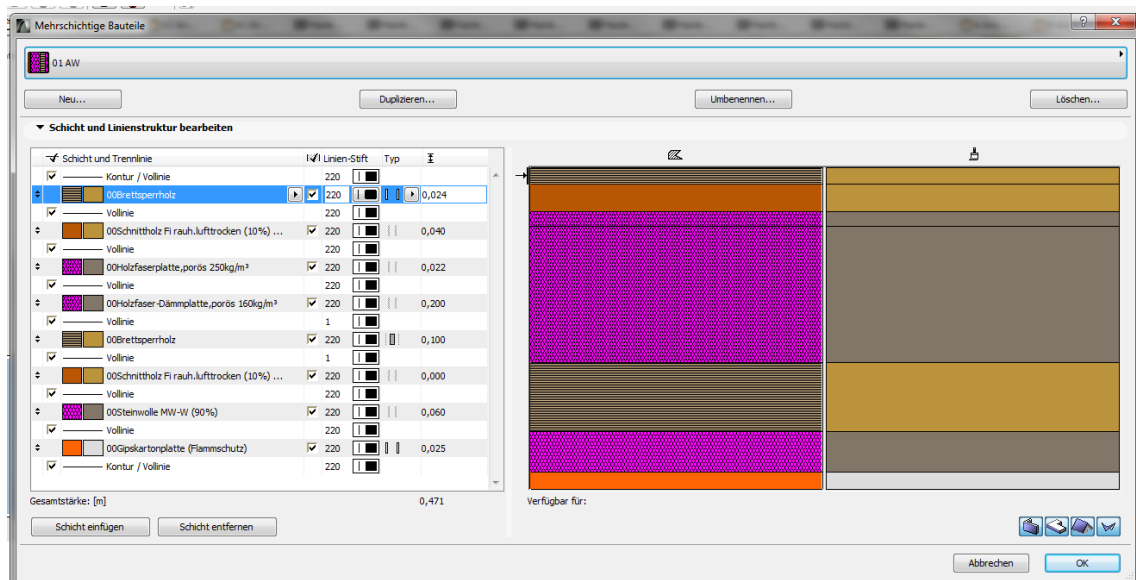


Figure 3: Multi-Layer elements – Parameterisation in Archicad

4.2 Life Cycle Assessment – A Comparative Study

After defining the multi-layer elements, two ways of carrying out the LCA were tested. In the first step the BuildingOne Database was tested, using BuildingOne plug-in in the Archicad. Initially a configuration was carried out, which we defined which building elements and properties should be exported to the database. To make this process easier, we created a layer combination called “OI3” in Archicad, which includes the building components relevant for the OI3-Index. Through this configuration, later mistakes, which can appear through synchronisation of wrong building components were avoided. Afterwards the multi-layer elements together with relevant parameters such as area, volume, layer (material) etc. were exported in the BuildingOne (Figure 4). In BuildingOne the elements were further parameterised through eco-indicators, which was carried out manually. However, due to the direct connection with the BIM model, all of the model-changes are synchronised with the database. For the calculation of the each OI3 Index indicator (GWP, PEI or AP) customised queries have to be compiled, as well as for the final calculation, which requires know-how and experience in the work with databases, which normally the designers and architects do not have. Finally the eco-efficiency report from the database can be exported in .xls for further processing.

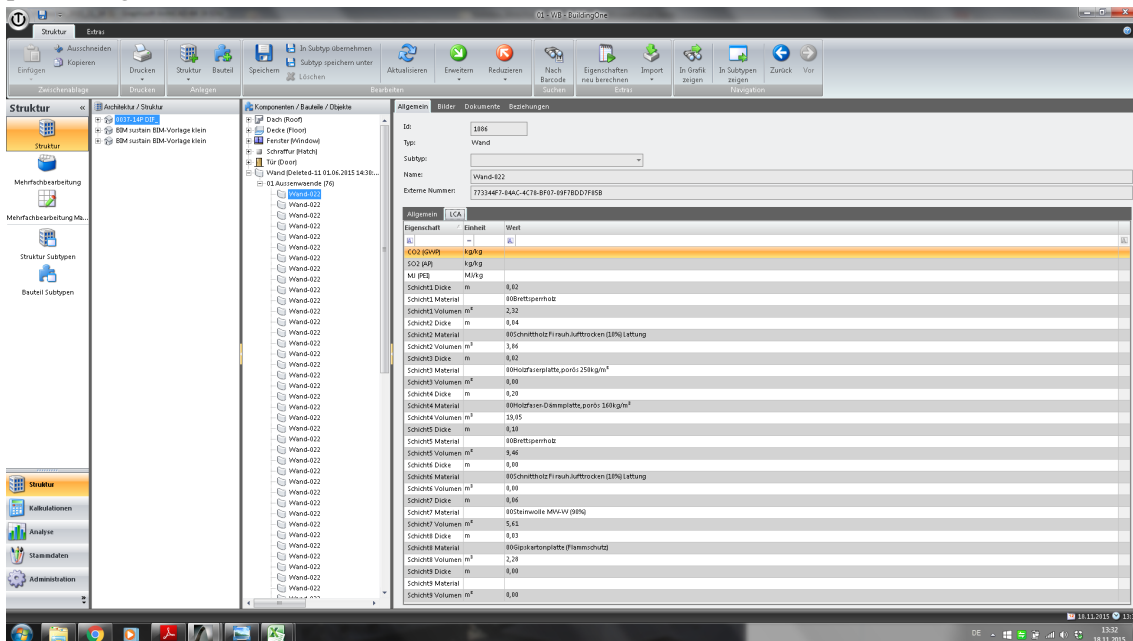


Figure 4: Data Management in BuildingOne

For comparison, the manual handling of data was carried out directly in .xls, where the originally compiled list of building elements and related eco-indicators was manually processed by adding the parameters such as areas and weight for final calculation of OI3 Index (sum of the parameters). The manual processing was easy and fast for handling, however due to the lack of automated synchronisation, prone to errors due to model-changes, such as areas, which had to be adapted manually. Figure 5 shows the comparative study, and advantages and disadvantages of both processes.

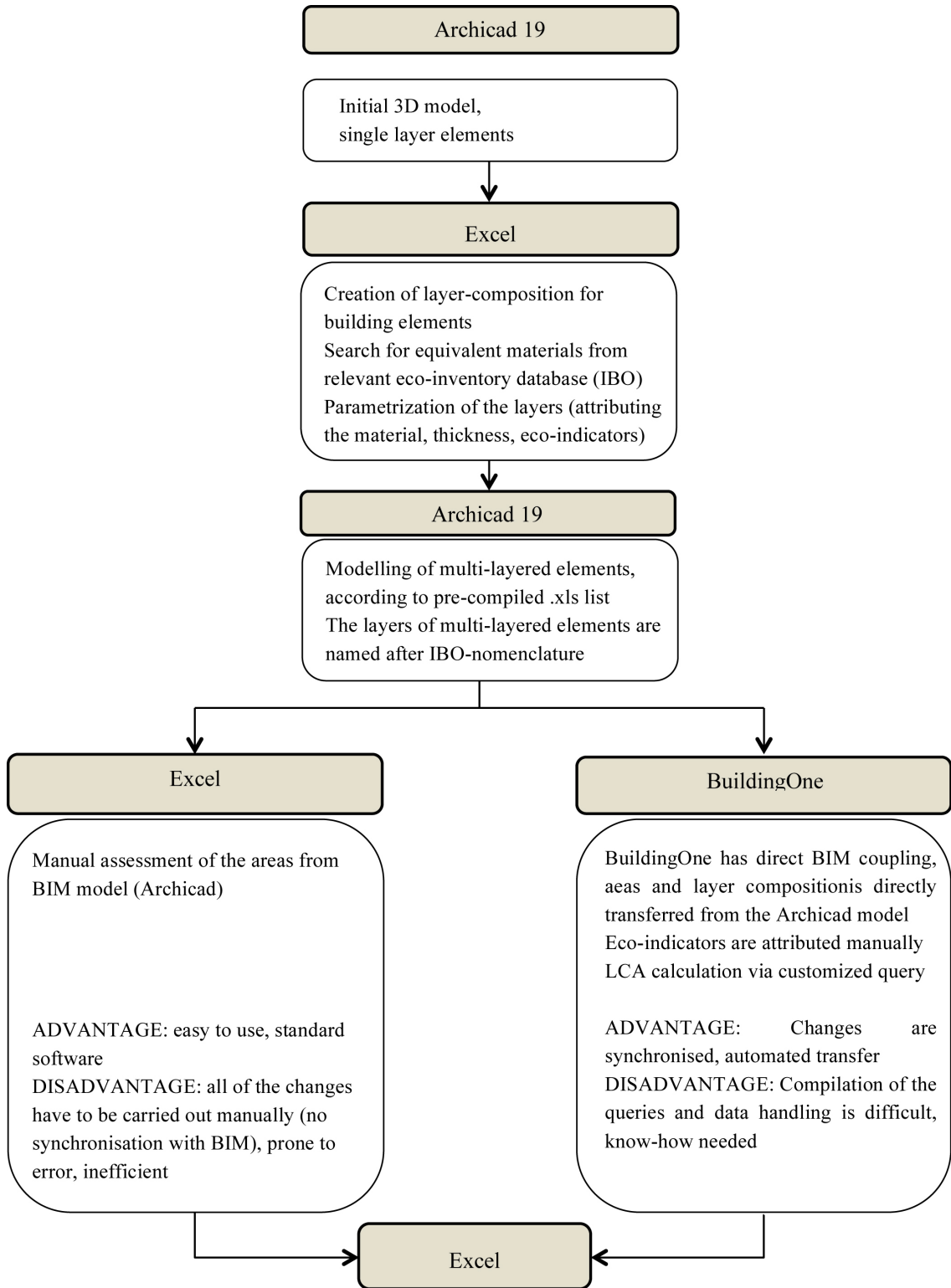


Figure 5: Comparative Study: LCA using BuildingOne and MS Excel

4.3 Structural Analysis

The primary focus of this study was to prove the data exchange efficiency between architecture (Archicad 19) and structural design and analysis (Dlubal REFM) modelling. The data and model exchange process still required model-repairs after the import in the structural analysis, despite the fact that the architect was instructed by the engineer about the required model-quality for the transfer. The work-flow analysis is presented in Figure 6.

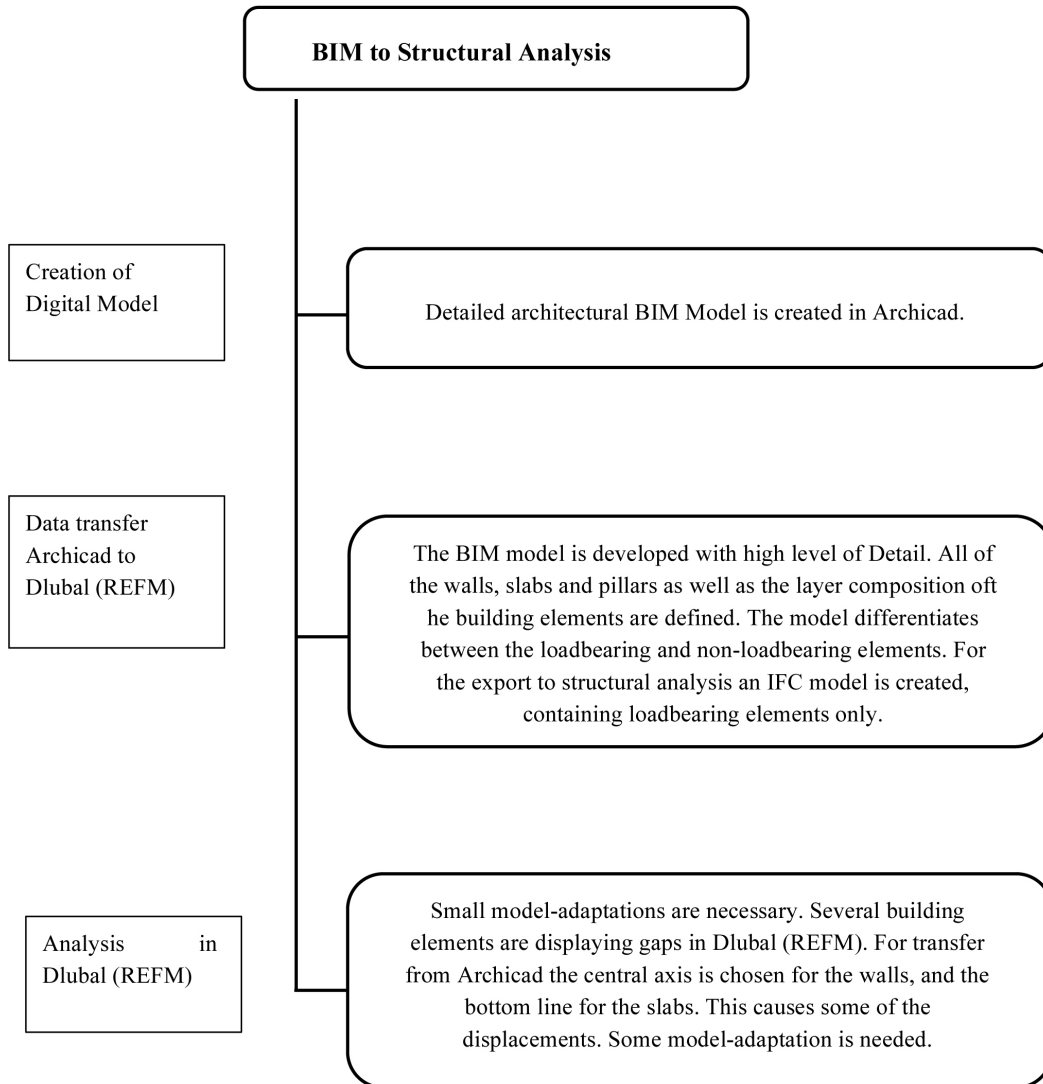


Figure 6: Structural Model before repair (slabs and walls intersecting)

In order to solve the lacking of geometrical intersection of various elements or of the wrong interpretations of geometry after export, model-repair had to be undertaken as shown in Figure 7.

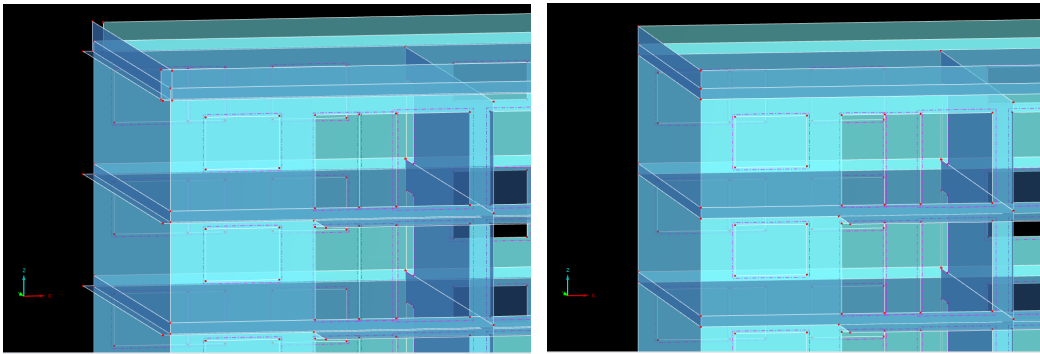


Figure 7: Structural Model before (Left) and after (right) repair (slabs and walls intersecting)

A development of a method for the discretization of geometry is here required, to bridge the semantical differences and varying needs in the modelling of architecture and structural engineering (e.g. slab-to-slab column in architecture; continuous column in structural engineering). The automation-procedures for model repairing and bi-directional exchange should be developed, in order to enable more effective interdisciplinary BIM supported design process.

5. Discussion

Despite of the intensive efforts of bodies such as buildingSmart (2015) or Austrian Standardisation Institute (ÖNORM A6241-2, 2015) to support interoperability through unification of building objects and their attributes (buildingSmart Data Dictionary – bSDD, 2015) there are large differences between the BIM data and the eco-inventories. Databases contain diverging descriptions (nomenclature) of building elements or materials, which again disables process-automation. Further on, manual parameterisation (attributing of eco-indicators) of materials of either multi-layer or single-layer elements in BIM model itself is not possible at the current moment (in Archicad 19). The elements contain some eco-indicator data already, however this data does not correspond to the Austrian LCA-Standard, nor are the system limits known (black-box problem), thereby the provided data is not valid for a sound LCA assesement.

BuildingOne has proved as potentially very useful tool. Due to the fact that its original purpose was cost accounting and area management and not LCA, some difficulties were encountered along the line of discussion above - some of the identical walls have a different identification number (attributed according to the position). A query for grouping of the elements must be compiled. A lot of effort is needed to customise the database, so if using such a tool, designers need skills and enhancement of capabilities.

As further general problem the Level of Development can be identified. The question remains in which Level of Development the model should be modelled for each life-cycle stage and for which specific purpose. The LOD 300 is defined by BIMforum (2013) as:

” The Model Element is graphically represented within the Model as a specific system, object or assembly in terms of quantity, size, shape, location, and orientation. Non-graphic information may also be attached to the Model Element. “

The problem encountered in the conducted case study, was that the various disciplines needed various detailing and data-richness of the model (e.g. LCA very detailed model, structural analysis very basic model), but in the same design-stage. This poses challenges on the designer. Thereby, an integrated process is needed where partaking disciplines can discuss model-needs for their specific purposes from the beginning, thus establishing project-related conventions, instead of relying on standards, which do not reflect the specific needs of the project. For example, if architect had not been working with structural engineer from the beginning of the process in the case study, it would not have been possible to provide a proper model. Thereby experience as well as interdisciplinary collaboration are two crucial factors for BIM supported analysis.

Further difficulty for LCA in general, however using BIM software in particular, is that the required Level of Development is often too high for such early design stage - all of the layers of the building elements have to be defined in order to attribute the eco-indicators, and carry out the follow up analysis. Often this cannot be done, because of the many unknown design-parameters in such an early design stage.

6. Conclusions

In this paper we have explored the potentials of BIM as joint knowledge base for the follow up life cycle assessment and structural analysis in the early design stage. Thereby various software tools were employed and workflows were analysed in terms of efficiency of data transfer and management, data-losses and ease of use. The comparative LCA-study has demonstrated that data-handling with standard software is easy, however prone to errors due to the numerous changes in the design which have to be adapted manually – the semi-automated process using BuildingOne database is more reliable in terms of change management, however requires skills and competencies of designers, which they normally do not have. Model-transfer to structural analysis required small model adaptations due to semantical differences in geometry, despite the interdisciplinary collaboration and coordination between the architect and engineer in terms of modelling.

We can conclude that integrated planning approach is necessary, where all of the members of design team work together from the beginning of the process, in order to discuss the specific Level of Detail as well as of Development needed for the follow up analysis. Standardisation process for creation of international reference libraries for digital products and materials has to be more intensified on transdisciplinary level, in order to enable the life cycle analysis of built environment.

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An Evaluation of BIM Opportunities in Design Phase of Donor-Funded Projects

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Abstract

The construction projects in developing countries have been negatively influenced by communication gaps and lack of interoperability in design and construction processes. BIMs appeared as an enablers of interoperability, but today the implementation of Building Information Modelling as an information management paradigm that spans over the projects' entire life-cycle provide unique opportunities for facilitation of the processes in all phases of the construction lifecycle. In order to explore the full potential of the implementation of the Building Information Modelling as an information management strategy, opportunity analyses covering different phases of the life-cycle is required. This paper focuses on providing an opportunity analysis to explore the opportunities provided by the BIM to facilitate collaboration and coordination in the design phase of construction projects.

Keywords: BIM, Opportunity, Design, Donor, Projects

1. Introduction

The construction projects in developing countries have been negatively influenced by communication gaps and lack of interoperability in design and construction processes. Some countries who are under economic and political pressures frequently face difficulties in completing the large projects. In a few of them such as Palestine (i.e. West Bank & Gaza Strip) government projects are funded by donor organizations due to county's difficult economic situation. Donor-funded construction is a rarely observed economical model for the construction industry and neither its processes nor the difficulties and opportunities contained in the model has been in the focus of built environment research. On the other hand, Palestine appears as a nice case which contains many cases of donor-funded projects. Key projects in Palestine depend on aid from donor countries and organizations. The bodies and organizations that offer grants to the construction industry in Palestine are the World Bank (WB), the Islamic Development Bank (IDB), the United Nations Relief and Work Agency (UNRWA), the U.S. Agency for International Development (USAID), United Nations Development Program (UNDP), the European Union (EU), German and Japanese institutions, Welfare Association and World Vision (Abdulahdi, 1994). The construction industry in Palestine is one of the key industries and is the main force motivating the Palestinian National Economy. The industry can be viewed as an advancement enabler for achieving nationwide goals in modern society In the country, the problems in construction projects are not only caused by the lack of technical skills and financial resources but also as a result of inadequate coordination, integration, communication and control of project activities.

The paper focuses on providing a review of opportunities provided by the use of Building Information Modelling in the design phase of donor-funded projects. The review provided in this paper is based on outputs of authors' previous research on i.) opportunities provided by the implementation of Building Information Modelling in several phases of the construction life cycle and ii.) exploring and mapping the processes of donor-funded construction projects. The latter effort was unique in terms of depicting and formalizing the processes of donor funded projects and also in terms of discussing how the processes in donor-funded projects can be facilitated by better communication and coordination between all stakeholders. The paper will summarize the results of this latter effort together with providing information on the opportunities provided by the utilization of Building Information Models. The paper starts by summarizing the construction industry in Palestine, including different contract types and actors. The 3rd section introduces the concept of process-based construction management. The 4th section discusses coordination problems in donor funded projects. The 5th section focuses on the details of the processes in the design phase of the donor-funded projects. The 6th section discusses the opportunities provided with BIMs in donor funded projects. The paper finalizes with a summary and conclusion section.

2. Overview of the Industry

The projects in the construction industry have a significantly high rate of business failure, and collapse and bankruptcy. The projects in the industry has been significantly affected by

economic, environmental and political cycles due to many uncertainties resulting from many players of multiple disciplines who are brought together at various stages throughout a single project (Enshassi et al., 2006). Palestine construction industry is not an exception to this. The industry is complex and influenced by factors which may cause weakness including changing economy, closures, mismanagement of projects and the lack of skills and technology (Enshassi & Abu Rass, 2008). Elbeltagi (2006) indicates that the construction projects in Palestine can be classified into four major categories as:

- *Residential Housing Construction* which includes single-family houses, multi-family dwellings, high-rise apartments.
- *Institutional and Commercial Building Construction* which encompasses a great variety of project types and sizes, such as schools, hospitals, sports stadiums, retail chain stores and large shopping centres.
- *Specialized Industrial Construction* such as oil refineries, steel mills, chemical processing plants and coal-fired or nuclear power plants.
- *Infrastructure and Heavy Construction* which includes projects such as highways, mass transit systems, tunnels, bridges, pipelines.

Different types of enterprises take part in the construction industry of Palestine, according to PCU (2003) these can be classified as,

- *Donor (International Financing) Enterprise* which appeared as a result of general economic situation and financial failures that prevented the completion of the projects.
- *Public Enterprise* which covers governmental institutions that owns or manages public projects.
- *Private Enterprise*

In construction projects, three main actors are present as (Elbeltagi, 2006):

- *Owner (Client)* can be a public or a private entity and is the body who funds the project as result of the donation received.
- *Designer* is the design professional, this group includes architects, engineers, and design consultants.
- *Contractor (The Construction Professional)* is the party who undertakes the responsibility of construction from the owner (Bockrath, 2000).

A Contract can be defined as an agreement between two or more parties that creates for each party a duty to do something (e.g., to provide goods/ a service at a certain price and according to a specified schedule for one party and to pay for the service provided for the other) (Owen, 2003). Construction contracts in the country can be classified into the following types as; General (Traditional) Method "Unit Price" Contracts, Cost Plus Contracts, Design-Build Contracts, Turnkey Contracts, Management-Oriented Contracts, Construction by Daily Labor Contracts, Target Estimate Contracts, Guaranteed Maximum Price Contracts, Construction Management Contracts, Lump Sum Contracts, (BOT) Build–Operate–Transfer Contracts, and Special Contracts. The selection of the contract type in Palestine depends on several factors such as government agency type, project type, and sponsor identity. Sometimes the local agencies are even enforced to use the contract template of the sponsor organization's country.

Based on the result of interviews that were conducted during this research, 4 different types of contracting methods were found to be actively in use as

- General (traditional) contract Method “Unit Price” Contracts
- “Special Contract Method” Contracts
- “Construction by Daily Labor” Contracts
- “Turnkey” Contracts

In addition, there are 2 more types that are in use which are the Lump Sum and (BOT) Build–Operate–Transfer Contracts but they are used less frequently.

3. Process Based Construction Management

Process Based Construction Management can be defined as the management of the activities in construction projects based on well-established processes which are formalized by process protocols, frameworks and models. A Process Protocol is a tool and methodology for formalizing the process in the construction industry. The formalization of the processes serves for better understanding of the flow of events and interactions between the parties, finally resulting in better coordination during the design and construction stages. The approach has its roots in systems engineering and total quality management, where each molecular level component of a business (i.e. a process) is identified in detail. This identification includes the identification of the activities (i.e. the atomic level business components), actors that take part in this process, the input and outputs of the process, and identification of the relations between different processes, between super and sub processes. U.K. and U.S institutions are the leading research bodies in this field. The U.K. Construction Industry Process Protocol is a well-known protocol and is based on a recognized process model. Process Protocol Website (2013) defines this protocol as “*a common set of definitions, documentations and procedures that provides the basis to allow a wide range of organizations involved in a construction project to work together seamlessly*”. In the model, construction processes are grouped in 4 main stages as pre-project, pre-construction, construction and post-construction. Then this stages are divided into ten phases. Also, the participants within the Process Protocol are organized into activity zones. As stated in Wu (2004), the major benefits of Process Protocol are:

- The archiving and retrieval of project information
- Rapid communications
- Effective co-ordination
- The visualization of client’s requirements
- The visualization of structural and spatial requirements

There are also process frameworks based on technology re-engineered processes, a key example of these is the framework presented in BIM Execution Planning Guide. This study outlines the re-engineered processes based on the use of specific information management approach known as Building Information Modeling (BIMPEPG, 2013). Identifying the process models helps in identification of deficiencies in process along with risks associated with these deficiencies. On the other hand process maps provides a clear understanding of processes, their sequence, and their relations with other process. This in turn provides a foundational framework for identifying

the opportunities related to each process. Following a review of the coordination related problems in the industry remainder of the paper will present a process map of design-phase activities in donor funded projects and discuss the opportunities provided by the BIMs in these type of projects.

4. Coordination Problems in Processes

Mohd Noor (2011) mentioned that 90% of all problems on site are due to late or inadequate information. Late information can cause thousands of dollar of losses in design and construction phases. In this research the identification of coordination related problems in donor-funded projects is accomplished by semi-structured interviews that were conducted with twenty experts including i.) engineers who work in government or NGO (non-governmental organizations) or at private engineering offices, ii.) contractors , and iii.) project managers. The interviewees were selected based on their experience in construction projects, In addition, they were working in different institutions and each have key positions in the government, in the contracting companies or at engineering offices. The interview process took over a period of two months. Open-ended questions most of which were prepared prior to the interview were used mainly as the interview instrument, and some emerging questions were asked spontaneously during the interview. Once the interview is concluded, the researchers analyzed the responses. The problems that were identified through literature review and problems appeared as the result of the interviews were grouped together, in six main groups, which are problems related to construction information, management, legal, financial dimensions, and included design phase problems and technical problems.

The construction information related problems were appeared in the form of problems related to the coordination due to; i.) lack of operational information such as change orders, ii.) unclear or contradictory information which is not comprehensive enough, iii.) incomplete drawings and documents, and iv.) problems in scheduling. The interviewees indicated that there exists gaps between the implementation of the drawings on site and the requirements in the specifications due to misinterpretation of drawings. Management problems are related with planning, controlling and so on. Unclear task specifications, problems in planning stage, and unpredictable changes in the project scope and requirements were identified as the key problems. The legal problems identified were i.) weakness in the harmonization of laws, and ii.) ambiguities such as legal disputes that emerge during the construction phase, iii.) changes that occur in government regulations and laws during the construction of the building. The financial problems were related to poor cost management and quantity surveying practices, and to the lack of cash flow management systems. The design phase problems include conflicts between consultants and design engineers, and uncoordinated (structural, mechanical, electrical) design. Finally, the technical problems were related to lack of technical support for the project, team and lack of human resources with required technical skills. Problems appeared as a result of rushed bidding process, and the use of obsolete technology in planning and construction stage were also reported during the interviews.

5. An Overview on the Design Phase Processes of Donor-Funded Projects

The Building Construction process in Palestine is initiated by the owner organization. The owner organization first indicates a requirement for a building to the responsible body of government, such as Ministry of Education, Ministry of Public Works and Housing. Then the government agency elaborates on this project idea, conducts a feasibility study and start to look for the financial authority that would support the project. As a result of the economic situation in Palestine, most of the projects depend on grants from donor countries or organizations. Once a donor is found and the support request for proposed project is approved by the donor the pre-design phase concludes. The donor organization then starts the transfer of the funds for the project through the Ministry of Finance. Most of coordination problems observed start in this phase, due to misinterpretation of clients' needs and due to problems in feasibility studies.

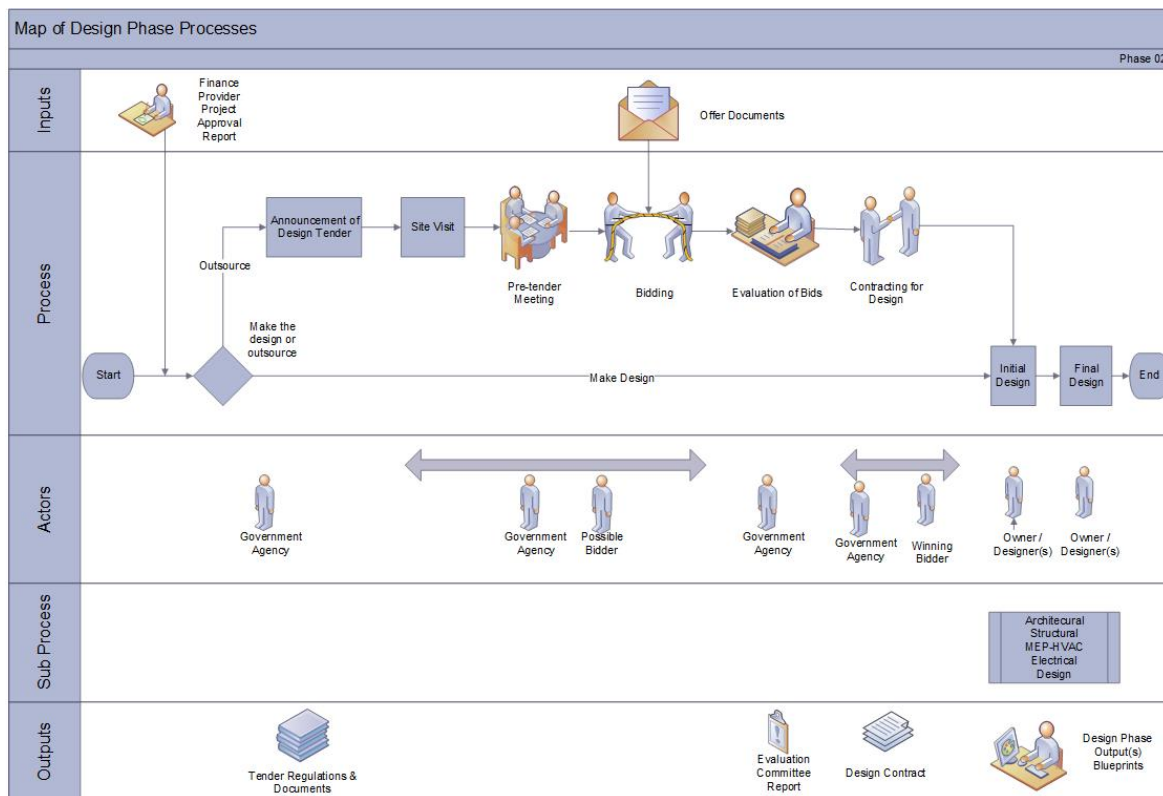


Figure 1. Design Phase Processes of Donor-Funded Projects

The following phase of the projects is the design phase. The process map for the design phase is shown in Figure 1. Once the government arranges the financing of the project at the pre-design phase there are two routes to follow. In the first one the Design and Supervision Department prepares the design, and the construction tender documents based on the client specifications, the conditions of the client and the budget allocated for the project. On the other route the design is delegated to a design consultant as a result of a bidding process. In this option the tender-for-design is announced in local newspapers in order to reach sufficient number of

bidders. This is followed by a visit to the site, and an initial meeting to respond to the information requests of the possible bidders before the tender is opened. Once the tender is opened and finalized, the evaluation of the bids is conducted by the Evaluation Committee of the Government Agency. A design development contract is signed with the winning bidder. The winner prepares design documents, and the documents required for the construction tender (including detailed design, BOQs and so on).

6. Opportunities provided by BIM for Design Phase Processes

The implementation of Building Information Modelling as an information management strategy covering the projects' whole lifecycle and as a design management approach would facilitate design processes by enhancing communication, collaboration and coordination between the stakeholders. The opportunity analysis presented here is prepared by narrowing down the coordination related problems identified in the earlier phase of the research based on the design phase processes presented in previous section. The opportunities provided can be grouped into 4 categories as provision of consistent information, provision of comprehensive information, nD capabilities of BIM and process facilitation through the implementation of BIM methodology, which are presented in Table 1. BIMs contain detailed and comprehensive information about the building elements, their materials and material properties, elements' current state, their relations with other elements. The information residing in the BIM is always consistent in terms of 3D geometry of building elements and their semantic attributes. Views (i.e. subsets) can be generated from the model on demand or periodically and blueprints can be automatically derived from the model. Thus there will not be any inconsistencies between the digital model and the shop drawings. Finally, BIM methodology (BIM as an information management methodology) will help the facilitation of different processes in the lifecycle of the building. Below presents an overview on how the coordination problems mention in Table 1. can be eliminated by using the BIMs.

Table 1. Opportunities provided by BIM in Design Phase Processes of Donor-Funded Projects

Causes of Coordination Related Problems	Opportunities Provided by BIM
Unclear or contradictory information which is not comprehensive enough	-Provision of Comprehensive Information
Incomplete drawings and documents	-Provision of Consistent Information
Problems in scheduling.	-nD Capabilities of BIM
Unclear task specifications	-nD Capabilities of BIM
Poor cost management and quantity surveying practices	-nD Capabilities of BIM
Conflicts between consultants and design engineers	-Provision of Consistent Information
Uncoordinated (structural, mechanical, electrical) design	- Process facilitation through implementation of BIM Methodology
Lack of technical support for the project	-Process facilitation through implementation of BIM Methodology
Lack of human resources with required technical skills.	-Process facilitation through implementation of BIM Methodology
Legal disputes that emerge during the construction phase	-Dispute resolution through implementation of BIM Methodology

Provision of comprehensive information: BIMs provide comprehensive information about all building elements including, geometric and semantic properties, their materials, to-be-built dates, and relationships between them. The information provided by BIM will help in removing the unclarified information representation and flows which occur during the construction processes.

nD Capabilities of BIM: The use of BIMs will help in increasing efficiency in scheduling with the help of 4D scheduling simulations, will facilitate processes by eliminating problems occur due to lack of clarity in design communication. The information contained in BIMs will help in building up better design workflows and better specification of design and construction related tasks. The semantic information contained in BIMs will facilitate the process of quantity take-offs. The implementation of automatic calculation of quantities will produce efficient inputs for the bidding phase in a timely manner. This in turn will be the first step for the better cost management practices.

Provision of consistent information: The BIMs contain 3D information with associated semantics where 2D drawings can be derived from it. During the construction of the BIM tools such as clash detection are used to prevent inconsistencies in the model. Thus the derived 2D models, and blueprints would eventually be components of complete and consistent design documentation. Thus the incompleteness in design documentation would be provided by the use of the BIMs. The BIM-derived shop drawings and design documents would contain detailed information about each building element together with details regarding the construction and assembly of the element, which in turn would be very helpful in preventing the conflicts between the consultants and designer which emerge in not well documented construction processes.

Process facilitation and dispute resolution through implementation of BIM Methodology: BIM methodology can be defined as an information management methodology that spans over the projects entire life cycle and focuses on management of the construction project based on the information derived from the BIMs. Building Information Modelling methodology proposes the use of design collaboration tools and software which would facilitate the coordination in the design process between architects, structural, electrical and mechanical engineers. The implementation of Building Information Modeling methodology will help in getting technical support in collaborative workspaces. The implementation of Building Information Modelling methodology requires highly skilled workforce on BIM related technologies and this generates the need for BIM training. An important impact of the training is development of a highly skilled workforce which in turn can be utilized in future projects. As indicated in Koc and Skaik (2014) the information derived from the BIM will be helpful in supporting the claims of the parties. In addition, BIM can also be helpful in dispute resolution through efficient representation of building elements that are related with the dispute. Furthermore, the 4D representation of the dispute event will contribute to the resolution efforts, as it will help the parties in evaluating the problem in focus in more detail.

7. Conclusions

The paper presented a structured review of opportunities provided by the use of Building Information Modelling in the design phase of donor-funded projects. The opportunities provided by the use of BIMs facilitate i.) design phase processes and ii.) processes which are dependent on design phase processes. The opportunities arise by the use of BIMs as shared information models and the implementation of Building Information Modeling as an information management methodology in the design phase. The BIMs provides comprehensive and consistent information which in turn enables better collaboration, communication and coordination of the design phase activities. The information contained in the BIMs are more reliable than conventional CAD models as BIMs contain agreed 3D geometries and semantic information, where sub models and other graphical representations (such as 2D) can be generated automatically. On the other had the implementation of Building Information Modelling as an information management method will also contribute to increase the skill levels of the employees, while providing a them a more efficient working environment.

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BIM in LCA/LCEA Analysis: Comparative analysis of Multi-family House and Single-family

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Abstract

The use of Building Information Modelling (BIM) in the Architectural, Engineering, and Construction (AEC) industry has increased lately due to the awareness of this methodology's potential to improve the performance and efficiency of projects and reduce errors. Similarly, there is a growing concern with energy consumption and environmental impact of buildings. If BIM is integrated with other methodologies that assess the environmental impact of buildings and its energy consumption, such as Life Cycle Assessment (LCA) and Life Cycle Energy Analysis (LCEA), it is possible to achieve higher levels of sustainability of the urban environment.

This paper (i) identifies which information LCA tools require and how to incorporate it in BIM objects, (ii) determine how that information can be incorporated in the BIM model, and (iii) perform an energy and environmental analysis of two different buildings and compare the results obtained in order to understand the impacts of designer's choices on the building's performance. The authors not only identify which information is required for an automatic LCA analysis of BIM-based projects, but also assess which phases and materials contribute the most for the environmental impact of buildings.

Keywords BIM; LCA; LCEA; multi-family house; single-family house

1. Introduction

The building sector accounts for 40% of energy consumption and 36% of carbon dioxide (CO₂) emissions in Europe, with a similar scenario in the United States (Commission 2015). As the building sector is the main contributor of greenhouse gas (GHS) emissions and a huge consumer of raw materials, it is extremely important to develop adequate legislation for construction, in order to achieve the Kyoto emission targets. In the case of EU, the goal is to achieve a 20% energy efficiency target, 20% share of energy from renewable sources until 2020, and reduce greenhouse gas emissions by 80-95% by 2050, compared to the levels of 1990 (Commission 2012).

If methodologies such as Life Cycle Assessment (LCA) and Life Cycle Energy Analysis (LCEA) are employed in the Architectural, Engineering, and Construction industry (AEC) the EU will more likely achieve these targets. The LCA methodology predicts how a building will perform during its lifespan, considering its entire life-cycle (environmentally focused) (ISO 2010). LCEA assesses the energy consumption of the whole project (energy efficiency focused), considering: (i) embodied energy, which is the amount of energy due to the process of production, construction, transportation, and possible renovations; (ii) operating energy, which is the amount of energy used to maintain the indoor air quality (IAQ) and thermal conditions of the inside environment through heating and cooling, as well as lighting and operating appliance; and (iii) demolition energy of the building, which is the energy required to demolish the building and dispose of the material (Cabeza et al. 2014). As the operating energy is responsible for about 80-90% of total energy consumption and environmental impact (EI) of a standard building during its lifecycle, it becomes crucial to choose the solutions that will enhance the energy performance of the building from the very first phase of the project (Asdrubali et al. 2013). This must be taken into account when we are performing an LCA or LCEA of a project, in order to achieve a sustainable construction.

Nonetheless, in order to fully use the potential of methodologies such as the ones described above in the AEC industry, an integrated approach capable of supporting all life cycle phases and gathering and processing a high volume of information is needed. Building Information Modelling (BIM) might be the solution for that problem. BIM is a methodology that enhances the collaborative aspect amongst all different fields of expertise throughout the project design and enables a more efficient management of a building's operation cost (Costa and Grilo 2015). The potential of BIM in the field of energy simulation and building performance has also been recognized lately, with applications ranging from photovoltaic (PV) simulation, waste management, energy rehabilitation of existing buildings, etc. (Ahn et al. 2014; Cheng and Ma 2013; Gupta et al. 2014).

Despite the growing amount of published papers in the last years regarding BIM synergies with energy and building performance (Hiyama et al. 2014; Marzouk and Abdelaty 2014; Woo and Menassa 2014), so far, the literature in BIM-LCA only analyses the theoretical advantages of this integration (Antón and Díaz 2014; Díaz and Antón 2014), with only three papers having a more empirical approach (Basbagill et al. 2013; Jalaei and Jrade 2014; Jrade and Abdulla 2012). Identifying this need for additional BIM-LCA discussion, the current paper focuses the integration between BIM

and LCA/LCEA tools, and reports an energy and environmental analysis of two different buildings and compares the results. The rest of the paper is structured as follows: section 2 describes the methodology used; section 3 identifies the required information for BIM-based LCA/LCEA; section 4 presents a pilot case study conducted to test existing tools for energy analysis and environmental performance of buildings, and in section 5 conclusions are presented.

2. Methodology

As mentioned above, the aim of this paper is to briefly discuss the integration of LCA/LCEA with BIM methodology and conduct an LCA study resorting to a pilot case study. As a result of this BIM and LCA/LCEA integration, this paper contributes to: (i) the efficient use of LCA and simulation methods in design processes, (ii) promotion of performance-based methods within designers, contractors, and providers of facility maintenance and energy services, and (iii) the improvement of product information management throughout the construction life cycle.

The first part of this paper describes the LCA and LCEA methodology and what type of generic information should be included in the BIM model. In this sense, the authors initially search for existing standards in the field of LCA and then identify the key information required to conduct an LCA study, and that should be included in the LCA databases.

In the last part of this paper, an LCA/LCEA is conducted using BIM-based software, using the pilot case study method. Two different solutions representing the residential buildings are analysed and compared: a single-family building and a multi-family building. Revit software is used to create the BIM models, while Revit Energy Analysis tool is used to conduct the energy analysis and Tally tool to perform the LCA study of the above mentioned solutions.

The results of the Revit Energy Analysis are based on the geometry and materials of the BIM model and automatically consider some predefined options based on ASHRAE standards (e.g. Occupancy Schedules and number of people living in the dwellings). The authors only specify the Analysis mode (“building elements”), the HVAC system (“Residential 14 SEER/8.3 HSPF Split Packaged Heat Pump”), the location (“Lisbon, Portugal”), and the building type (“single” or “multi-family”). The obtained results are then imported to Tally in order to consider the environmental impact of operation phase, and the impact assessment method used is TRACI 2.1.

3. BIM and LCA/LCEA tools Integration

3.1. Definition of LCA/LCEA

According to AIA (Bayer et al. 2010), the LCA methodology have almost 50 years, when researchers demonstrated their concerns over the resources depletion and energy waste, searching for new ways of sustainable lifestyle (Adalberth 1997; Bekker 1982; Sharma et al. 2011). LCA’s potential started to be noticed only in 1997 with the International Organisation for Standardisation (ISO) publishing a set of

standards promoting the adoption of LCA method and presenting a framework for conducting an LCA analysis, with four phases (ISO 2010):

- The scope of an LCA: depends on the subject and the intended use of the study,
- The life cycle inventory analysis phase (LCI phase): consisting of the inventory of input/output, involving collection of the data necessary to meet the goals of the defined study,
- The life cycle impact assessment phase (LCIA): provides additional information to help assess a product system's LCI results,
- Life cycle interpretation: the results of an LCI and/or an LCIA are discussed as a basis for conclusions, recommendations, and decision-making in accordance with the goal and scope definition.

Although LCA method has been used in a variety of sectors for a long time, it was studied only in the last decade in the AEC sector (Antón and Díaz 2014; Buyle et al. 2013; Díaz and Antón 2014; Jade and Abdulla 2012). As LCA is a very consistent tool to evaluate environmental impacts, the AEC industry is increasingly incorporating this method and suitable product selection into decision making processes in order to optimise the whole construction process (Asdrubali et al. 2013).

In addition to the LCA method, there are other methods that assess the environmental impacts of constructions, such as Life Cycle Energy Analysis (LCEA) and Life Cycle Cost Analysis (LCCA). Unlike the LCA methodology, LCEA is more focused on the energy inputs of a building during its life cycle, including the embodied energy, operating energy, and demolition energy (Cabeza et al. 2014), and the sum of all the energy consumed in the building is the life cycle energy (Ramesh et al. 2010). Designers that resort to LCEA are able to identify the phases that have the highest energy demands, having the possibility to make more appropriate material choices. LCEA can also quantify GHG emissions through the primary energy of the building by multiplying it by a factor. However, LCA tools provide more precise results (Ramesh et al. 2010), as in this methodology, the product's environmental impact is assessed from the beginning of the analysis.

In order to successfully design a sustainable building with better performance, the designer not only should use BIM, as it is a methodology that has the ability to analyse different scenarios faster than the traditional methodologies, but also take into account a great diversity of different simulations, such as (Krygiel and Nies 2008): (i) Building orientation, (ii) Building massing, (iii) Daylighting, (iv) Water harvesting, (v) Energy modelling, (vi) Renewable energy, and (vii) Materials. As such, the designer must be aware which type of information fed into the BIM model will have a greater impact on the results of the LCA analysis.

3.2. Information required for LCA/LCEA tools

One source for LCA/LCEA tools databases is the Environmental Product Declaration (EPD), legislated and harmonised with the EN 15942:2011. EPDs have the purpose of facilitating the communication of a product's environmental performance for business-to-business (B2B) (Standards 2011). LCA can use generic, average, or specific data (Silvestre et al. 2015), with EPDs fitting in the last category. Specific data is the data collected at the manufacturer's plant. However, the product's

impacts can differ from other similar products (Silvestre et al. 2015). This is easily explained, as for the same products different manufacture processes can be used. If a manufacturer intends to develop an EPD of a product, the following information must be provided (Standards 2011): (i) General information of the product; (ii) Parameters describing the environmental impacts of the product; (iii) Parameters describing the resource use and primary energy use of the product; (iv) Parameters describing the resource use, secondary materials and fuels, and use of water of the product; (v) Information regarding waste categories of the product; (vi) Output flows of the product; (vii) Additional technical information; (viii) Additional information on release of dangerous substances to indoor air, soil, and water during the use phase.

In order for BIM-based tools to perform an automatic or semi-automatic LCA of a project, BIM objects must therefore contain the information described above. If manufacturers include that information in BIM objects, there will be no need to connect to specific LCA databases, promoting the open access to environmental information, as most LCA databases are paid. Also, it will be much faster and simpler to execute an LCA study in this situation, as designers will not need to learn how to work with additional tools. However, there are some data that designers should add in the BIM objects that are site-specific (e.g. energy and water used, site location, transportation from factory to site, etc.). In order to include the required data in BIM-based objects, manufacturers and designers can resort to parametric modelling, which allows to incorporate the information regarding different specialities in a single object, as well as defining parametric relations and constraints (Lee et al. 2006). International guides for a BIM object library should be used in this process, such as NATSPEC BIM Object/Element Matrix and NBS BIM Object Standard.

4. Pilot Case Study: multi-family house vs single-family house

The purpose of this pilot case study was to understand the effect of designer’s choices in the environmental impact of the building and to compare the energy consumption and environmental impact of a multi-family house with a single-family house, according to Figure 1. As such, the authors used Autodesk Revit to develop the BIM model, Revit Energy Analysis for energy simulation, and Tally for environmental assessment of the projects, as explained in Section 2.

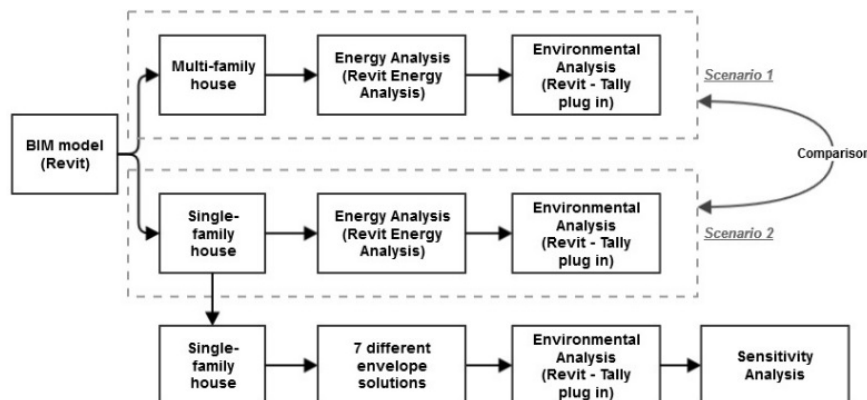


Figure 1 – Pilot Case Study methodology

The initial step was to model two simple buildings in Revit (Figure 2 and Figure 3), both with same envelope solutions, in order to guarantee that the results obtained are independent of material choices. After the development of both BIM models, the authors used the Revit Energy Analysis option to simulate the energy consumption (Table 1) and Tally plug-in to perform the LCA of these projects (Table 2), assuming a 60-year lifetime. Unfortunately, Tally plug-in did not recognise the chosen materials in Revit, only the construction solution, as this tool only works with GaBi's database. Extra work was therefore required in order to select the corresponding materials in Tally's database. This could compromise the accuracy of the expected results, as the tool users can select only the available materials. Nonetheless, as the purpose of this paper is to compare two scenarios with the same materials solutions, this software limitation will not jeopardise the expected results (both in Revit and Tally).

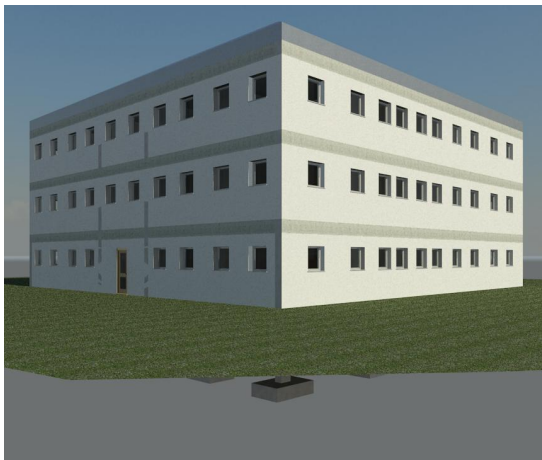


Figure 2 - 3 floor multi-family house (3D view)



Figure 3 - single-family house (3D view)

The second step of this Pilot Case Study was to analyse the environmental impacts due to materials selection, by examining the results of seven different envelope solutions (Figure 1). Unlike the first step, in which the authors' objective was to compare the energy and environmental analysis of different types of buildings, in this step the authors seek to understand the impact of designer's choices of materials, using a single scenario (single-family house).

Table 1 - Revit Energy Analysis results (multi-family house vs single-family house)

	Multi-family house	Single-family house	Units
Area	1,120.00	100.00	m2
Electricity Use	88.00	90.00	kWh/m2/year
LC Electricity Use	2,956,800.00	270,000.00	kWh
	270.0	24.7	kWh/day
PV low efficiency	46,514.00	11,243.00	kWh/year
PV medium efficiency	93,029.00	22,487.00	kWh/year
PV high efficiency	139,543.00	33,730.00	kWh/year

Table 2 – Tally results (multi-family house vs single-family house)

	Row Labels	Sum of Acidification Potential Total (kgSO ₂ eq)	Sum of Eutrophication Potential Total (kgNeq)	Sum of Global Warming Potential Total (kgCO ₂ eq)	Sum of Ozone Depletion Potential Total (CFC-11eq)	Sum of Smog Formation Potential Total (kgO ₃ eq)	Sum of Primary Energy Demand Total (MJ)	Sum of Non-renewable Energy Demand Total (MJ)	Sum of Renewable Energy Demand Total (MJ)
Multi-family house	End of Life	75	41	174960	0.00	2550	575515	569443	6046
	Maintenance and Replacement	3114	366	319574	0.01	17084	3840682	3309445	531238
	Manufacturing	5364	468	1285760	0.10	48229	10458306	9612019	846288
	Operations	12200	630	2635708	0.00	142650	59812579	36338720	23473859
	Total	20754	1506	4416001	0.12	210514	74687083	49829627	24857430
Single-family house	End of Life	-2	4	39813	0.00	149	42730	41394	1329
	Maintenance and Replacement	282	34	26429	0.00	1457	339942	291080	48862
	Manufacturing	567	49	192020	0.02	5358	1033348	940644	92704
	Operations	1100	57	222181	0.00	13750	5201615	3060519	2141097
	Total	1948	143	480442	0.03	20715	6617635	4333636	2283992

As it is possible to observe from Table 2, Tally provided six different Environmental Impact categories: Acidification Potential, which causes fish mortality, forest decline, and the deterioration of building materials; Eutrophication Potential, which can cause an undesirable shift in species composition; Global Warming Potential, which causes an increase of the greenhouse effect; Ozone Depletion Potential, which leads to higher levels of UVB ultraviolet rays; Smog Formation Potential, which leads to respiratory issues and damage to ecosystems; and Primary Energy Demand, which measures the total amount of primary energy extracted (non-renewable plus renewable resources). In general, the environmental impacts from the multi-family house are about 10 times higher than the single-family house, being almost proportional to the area of the building.

The Global Warming Potential (GWP) is one of the most relevant impacts, and in both cases it is mostly due to operational energy consumption. However, for the single-family house the weight of the operational phase is lower than for the case of the multi-family house. On the other hand, the manufacturing processes contribute more to the GWP of the single-family house than the GWP of the multi-family house. So, we might argue that there is an economy of scale in terms of manufacturing (as an example we can refer that there are several construction elements, such as foundations, roof, etc., that are not proportional to the number of floors) but in terms of operational energy consumption the same logic does not apply, as the multi-family house has higher relative energy consumption (what might be related to the relevant energy consumption of the common/social spaces).

It is also important to understand which kind of materials have higher environmental impact, and if these materials represent a considerable portion of the building's mass. Table 3 and Figure 4 display

the environmental impact of all materials used in the single-family house, throughout the different project phases. For this purpose, it is meaningless to display both scenarios (multi-family house and single-family house), as our real concern is only to analyse the environmental impacts due to materials selection, not to compare the two scenarios.

Table 3 - Tally (single-family house material's EI)

	Building Phases	Sum of Acidification Potential Total (kgSO ₂ eq)	Sum of Eutrophication Potential Total (kgNeq)	Sum of Global Warming Potential Total (kgCO ₂ eq)	Sum of Ozone Depletion Potential Total (CFC-11eq)	Sum of Smog Formation Potential Total (kgO ₃ eq)	Sum of Primary Energy Demand Total (MJ)	Sum of Non-renewable Energy Demand Total (MJ)	Sum of Renewable Energy Demand Total (MJ)
Single-family house	End of Life	-2	4	39813	0.00	149	42730	41394	1329
	03 - Concrete	17	2	3676	0.00	304	61060	58499	2561
	04 - Masonry	4	1	792	0.00	65	13189	12642	547
	05 - Metals	-19	0	-3730	0.00	-200	-39564	-39987	423
	07 - Thermal and Moisture Protection	-5	0	39061	0.00	-40	12243	10165	2072
	08 - Openings and Glazing	-1	1	-518	0.00	-28	-12902	-8244	-4658
	09 - Finishes	3	0	532	0.00	48	8704	8320	384
	Maintenance and Replacement	282	34	26429	0.00	1457	339942	291080	48862
	03 - Concrete	0	0	0	0.00	0	0	0	0
	04 - Masonry	5	0	654	0.00	29	7244	6854	391
	05 - Metals	235	31	16334	0.00	990	246946	211625	35321
	07 - Thermal and Moisture Protection	2	0	180	0.00	7	1088	770	318
	08 - Openings and Glazing	10	1	1943	0.00	120	35210	23277	11933
	09 - Finishes	30	1	7318	0.00	312	49453	48554	899
	Manufacturing	567	49	192020	0.02	5358	1033348	940644	92704
	03 - Concrete	181	7	40938	0.00	2402	290957	277781	13177
	04 - Masonry	19	1	11139	0.00	295	138240	130311	7928
	05 - Metals	283	33	25320	0.00	1725	364925	324893	40031
	07 - Thermal and Moisture Protection	53	7	105754	0.02	544	158259	143472	14787
	08 - Openings and Glazing	12	1	2455	0.00	147	47947	31358	16589
	09 - Finishes	19	1	6413	0.00	246	33021	32828	192
	Operations	1100	57	222181	0.00	13750	5201615	3060519	2141097
	Grand Total	1948	143	480442	0.02	20715	6617635	4333636	2283992

As expected, concrete was the material with the highest mass percentage of the building, having a relatively low environmental impact/mass ratio (except in the manufacturing process). On the other hand, metal-based materials and insulation materials have a very high environmental impact/mass ratio, particularly on GWP, Acidification Potential, and Eutrophication Potential, despite their low

representativeness in the total mass of the building. If designers are aiming for sustainable solutions, the selection of insulation material and its thickness is an extremely important aspect for the environmental impact of a building. It is relevant to mention that the higher the insulation thickness, the less thermal loss, leading to a decrease of operational energy consumption. So, for a sustainable solution to be reached, it would be advisable to perform a multi-objective optimisation of both (environmental vs energy consumption).

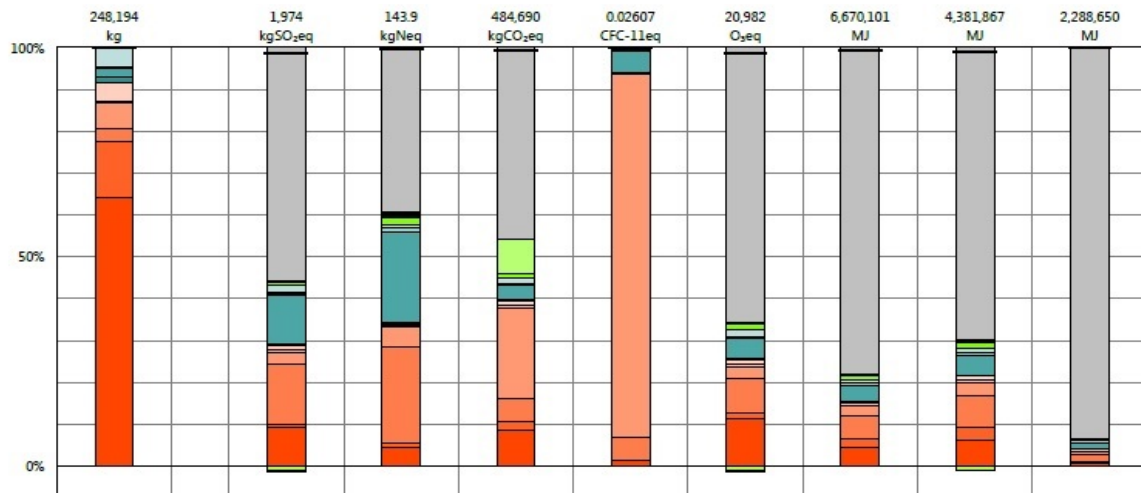


Figure 4 - Tally (single-family house material's EI)

Legend

— Net value (impacts + credits)

Manufacturing

- 03 - Concrete
- 04 - Masonry
- 05 - Metals
- 07 - Thermal and Moisture Protection
- 08 - Openings and Glazing
- 09 - Finishes

Maintenance and Replacement

- 03 - Concrete
- 04 - Masonry
- 05 - Metals
- 07 - Thermal and Moisture Protection
- 08 - Openings and Glazing
- 09 - Finishes

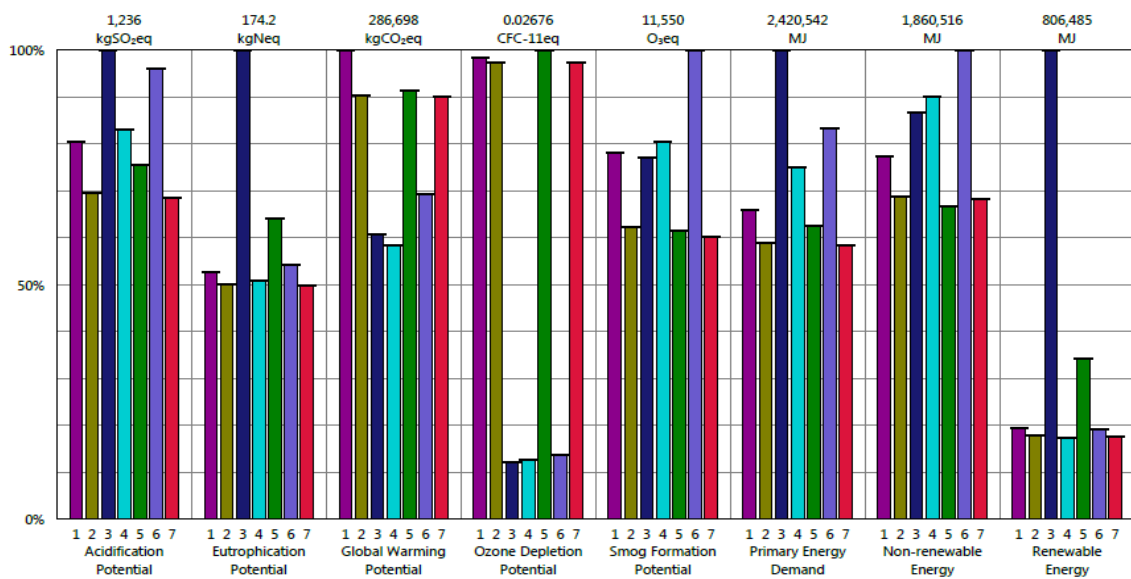
End of Life

- 03 - Concrete
- 04 - Masonry
- 05 - Metals
- 07 - Thermal and Moisture Protection
- 08 - Openings and Glazing
- 09 - Finishes

Operations

- Electrical + Thermal

However, in order to demonstrate how the designer's choices can profoundly affect a building's environmental impact, the authors decided to use the scenario of a single-family house and select different Revit and Tally solutions for the envelope. As observed in Figure 5, the original option (studied earlier) is one of the best sustainable solutions for most environmental impact categories. Also, wood-based solutions (option 3 and option 5) are the ones in which renewable resources can suppress most of the required Primary Energy Demand. Interestingly though, these two solutions also seem to be amongst the least environmentally friendly solutions (option 3 – wood roof: 1st in Acidification Potential, 1st in Eutrophication Potential, and 1st in Primary Energy Demand; and option 5 – timber floor: 2nd in Eutrophication Potential and 2nd in Global Warming Potential). However, if we examine Figure 6, we can conclude that most of those environmental impacts result from the End of Life potential use (recycling/reuse/recovery) of wood-based solutions, assuming that these materials are still in good condition. They are also the only ones with a positive energy return at the end of life (through burning processes). Regarding Smog Formation Potential, Acidification Potential, and demand from non-renewable resources, option 6 (full concrete envelope) comes as the least environmentally friendly solution.

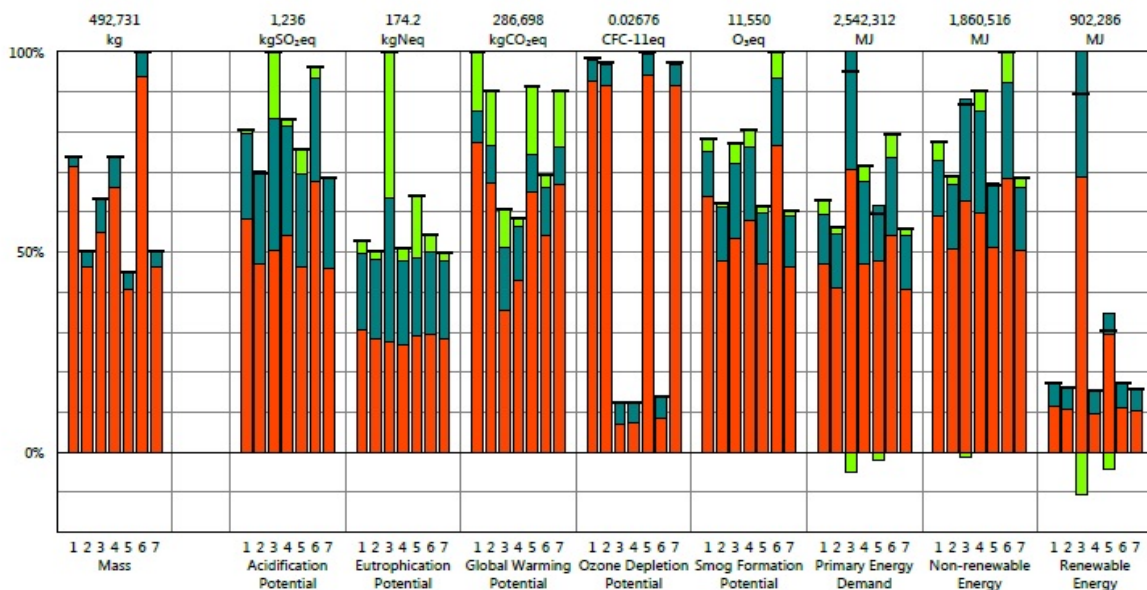


Legend

Design Options

- Option 1 - Concrete Walls
- Option 2 - Bigger Windows
- Option 3 - Wood Roof
- Option 4 - Concrete Roof
- Option 5 - Timber Floor
- Option 6 - Concrete Floor/Wall/Roof
- Original (primary)

Figure 5 - Tally LCA analysis of single-family house (7 different options)



Legend

— Net value (impacts + credits)

Life Cycle Stages

- Manufacturing
- Maintenance and Replacement
- End of Life

Design Options

- Option 1 - Option 1 - Concrete Walls
- Option 2 - Option 2 - Bigger Windows
- Option 3 - Option 3 - Wood Roof
- Option 4 - Option 4 - Concrete Roof
- Option 5 - Option 5 - Timber Floor
- Option 6 - Option 6 - Concrete Floor/Wall/Roof
- Option 7 - Original (primary)

5. Conclusions

The first purpose of this paper was achieved through the analysis of existing ISOs and ENs, in which EPDs were identified as one of the main sources for LCA's databases. As such, in order to develop a BIM-based LCA automatic simulation tool, BIM-based objects must contain some crucial information that is requested by EPDs (see Section 2). The LCA plug-in used in this article, in spite of identifying Revit elements present in the project, did not recognise the object's information, as it works with GaBi's databases. This means that all information used by this tool must be manually added by the user after designing the architecture and type of solutions in the Revit. The second goal was achieved by performing Revit Energy Analysis, in order to obtain the expected energy consumption of both multi-family house and single-family house, and then by performing an LCA by using Tally. As mentioned above, the authors had to manually add the energy consumption of the selected scenario (provided by Revit Energy Analysis) with the purpose of obtaining results due to Operational phase, and also manually add the materials chosen to be used in the construction of the building, from a pre-defined list.

Despite the innovative environmental approach of Tally plug-in, designers will be greatly limited by existing options. However, the designers must also bear in mind that Tally plug-in represents only a quick and approximate analysis of a building's environmental impact. The authors initially assessed that both multi-family house and single-family house had a similar energy consumption (kWh/m²), with multi-family house having about 10 times greater area, higher energy consumption, and greater environmental impact in most categories. The authors concluded that there was a positive correlation (in most cases) between energy consumption and environmental impact of buildings. Lastly, after the analysis of several envelope solutions for the single-family house scenario, the authors identified some effects due to the designer's material choices. Wood-based solutions are those in which renewable resources can potentially suppress most of the required Primary Energy Demand. Wood-based solutions are also those with higher End of Life potential use, leading to greater environmental impacts due to recycling/reuse/recovery processes. Option 6 (full concrete envelope) is one of the worst solutions, being on top of Smog Formation Potential, Acidification Potential, and demand from non-renewable resources. This is explained by the concrete's manufacturing environmental impact, which is very high compared with other materials.

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Benchmarking the Thermal Performance of GUtech's EcoHaus by Dynamic Modelling

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Abstract

The Sultanate of Oman is facing rapid population growth, fast urbanization and a steeply increasing energy demand. A major load is the cooling energy necessary for the ever-growing number of single-family houses in the hot and humid climate. In order to develop solutions to this pressing issue, the German University of Technology in Oman (GUtech) has designed and built a net-zero-energy residential building, the EcoHaus. The objective of this study is, to benchmark the thermal behaviour – and in conclusion the cooling energy demand – of the EcoHaus against the cases of buildings built according to the building regulations as well as according to the standard building practice.

The calculations are based on a dynamic model, which reflects the geometry of the EcoHaus and uses approved methods of heat transfer. The model is implemented in a MATLAB® simulation code, which is used to calculate summer- and winter scenarios. The most interesting results are summarised and discussed. These are the stand alone behaviour of the house, the energy balance of the inner air volume and the temporal cooling load as well as the cooling energy demand in the summer scenario.

The study shows that the EcoHaus achieves major energy savings in comparison with the chosen cases, which is founded in the (passive) design strategies. Furthermore, it was found that the house can keep the air temperature stable over a long period of time. The benefits in comfort conditions are significant and surmount the conditions in a standard house, although the energy demand is lowered.

Keywords: Benchmarking, Net-zero-energy building, Building simulation, Hot climate, Oman

1. Introduction

The Sultanate of Oman is facing a rapid urbanization with half the housing stock built within the last decade (Al-Awadhi 2007; Asif, Sharma et al. 2015). With view of the demographic situation and the current land distribution policies, this trend is likely to continue. About half the population is under the age of 30 years (Department of Economic and Social Affairs of the United Nations 2015) and every citizen is eligible for a plot of 600 m. at the age of 21 years; a trend that accelerates the urban growth and energy demand. The predominant house design is based on the building typology of the free-standing single-family house, and the predominant construction method is a reinforced concrete frame with a single-layered infill of concrete hollow blocks without further insulation on walls, roof, or windows. This standard low-cost design solutions and construction methods neither address the climatic conditions, such as the very high temperatures (up to 45 °C) and high humidity (up to 90 %) in summer (Dorvlo and Ampratwum 1998), nor do they link to the cultural traditions, in which a high degree of privacy in the house is required. The result of the first is high energy consumption for cooling buildings to reach comfortable interior conditions. With depleting availability of fossil fuel resources within the country and decreasing income generated from exporting these resources, the high subsidies for electricity consumption are questioned. The need for better solutions is obvious, and there are first initiatives to address this problem.

In 2011, The Research Council of the Sultanate of Oman (TRC 2015) gave grants to five universities in the country to design, build, operate, and monitor a net-zero-energy residential building on their campus. The project of the German University of Technology in Oman (GUtech), the EcoHaus, was completed in 2014. It is recognized as a successful contribution through national and regional awards for its concept, design, construction, and also the involvement of students.

While data of the actual performance of the house still being logged, this paper presents a dynamic model, which is used to simulate the assumed performance. With this, a benchmarking of the EcoHaus as an as-built case is undertaken against two other cases, the case of a building according to the building regulation requirements as well as the case of the actually used standard construction system. Not many such studies are undertaken in hot climates, especially not in the region. One example is the 'Baytna'-project in Qatar, in which two identical villas are built adjacent to each other - one built to usual standards and the other to "Passivhaus" standards - to allow for a comparison of their performances. The results of this benchmarking, however, are not published yet (Qatar Foundation 2015). Ochoa and Capeluto investigated the effect of an implementation of active- (e.g. blinds, lighting control and forced night ventilation), passive- (e.g. fixed shading, low-emissivity glass, or natural night ventilation) and a combination of both strategies in an office building in Haifa, Israel (Ochoa and Capeluto 2008). They found an energy saving potential of around 50-55 % in comparison with the actual building and stated a necessity to include energy saving strategies in early stages of the design process.

2. Model

The benchmarking is based on a dynamic model of the EcoHaus reflecting the geometry and the heat transfer properties of the basic building components. In this modelling approach, the house is divided in two parts, the envelope and the inner volume. The inner volume is divided in the solid volume that stands for all inner walls and other thermal masses within the building, and the air volume. The air volume temperature is the command variable of the model. Figure 2.1 shows the floor plans of the EcoHaus, where the parts of the envelope and of the solid volume can be distinguished: the inner surface of the envelope that is in heat exchange with both, the solid volume and the air volume, and the outer surface that is in heat exchange with the environment. For both surfaces, heat transfer by convection as well as by radiation is considered, while the heat conduction in the wall is solved according to the Binder-Schmidt-method. The envelope is discretized in circumference to picture the irradiation in dependence of the sun position. The same pattern is implemented for the roof as well as for the windows, where in addition the sun light transmission is considered.

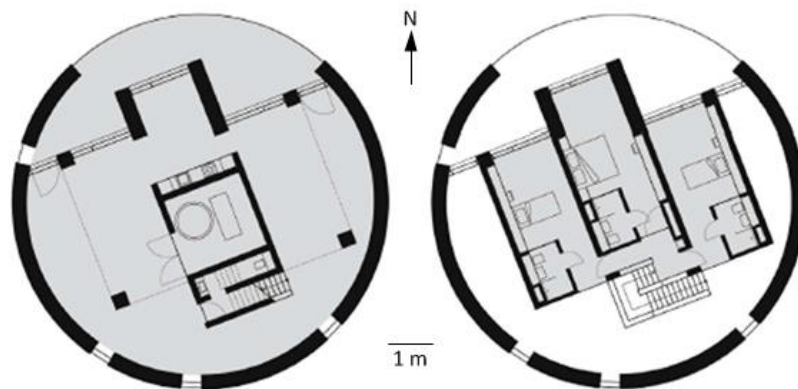


Figure 2.1: Floor plans of the EcoHaus

The model is implemented in a MATLAB® simulation, which is discretized in sufficiently small time steps. Due to this dynamic approach, the model can perform beyond estimations, which includes static temperature conditions and a steady state temperature profile in the wall. In the approach presented in this work, the thermal capacity of the wall and the dullness of heat transfer effects get considered in a sufficient way.

The most important input parameters for the simulation are the weather data and the material data for all reflected house parts. As weather data, including the hourly sun position, direct and diffuse sun radiation and environmental temperature, periodic input signals are used. The necessary values for the materials are the heat conduction coefficients, the density, the heat capacity and the minor geometrical information like the wall thickness.

The equations for different kinds of parts are simulated in modules. A superordinate code compounds the modules in a specific way for the EcoHaus geometry. The details of the model set-up will be presented in another publication. The focus of this study is on benchmarking the EcoHaus.

3. Case study

3.1 Material properties

The objective of this study is to benchmark the EcoHaus's performance in terms of energy consumption and indoor comfort conditions against common building types in Oman. In the comparison, the building material and material quality is changed for the outer walls, the roof and the windows – hence the envelope – according to these building types. The major geometry stays the same due to the code architecture of the superordinate simulation code.

To define the cases, information about the material properties has to be collected from different sources and a quantity for the differences between the envelopes in each case is needed. In architecture and civil engineering, the use of the U-value to quantify the heat transfer properties of a wall is usual. This value is quite useful to have a direct comparison of different structures. The static heat flow can be calculated in dependents on the air temperature on both sides and with an assumed steady state temperature profile in the wall. It therefore not only pictures the material properties, but the convection coefficient on the surface as well. As the simulation is transient, however, the convection coefficient changes with each time step and the thermal properties of the wall are pictured by the conduction coefficients (and heat capacities) of the wall only, which are fixed material properties. To gain a quantity capable of comparison of the heat transfer properties in the transient approach, the U*-value is introduced in equation (1). With this, the heat flow can be calculated in dependents on the surface temperatures of the wall. For a multi-layer wall it is given by

$$U^* = \frac{1}{\frac{\delta_1}{\lambda_1} + \frac{\delta_2}{\lambda_2} + \dots + \frac{\delta_n}{\lambda_n}} \quad (1)$$

with δ as the layer thickness and λ as the certain heat conduction coefficient. The U-value is

$$U = \frac{1}{\frac{1}{\alpha_I} + \frac{1}{U^*} + \frac{1}{\alpha_O}} \quad (2)$$

with α_I as the heat transmission coefficient on the inside boundary and α_O on the outside. With this distinction, the cases are defined as following.

Case 1 “as built” is the EcoHaus in the actually build condition. The wall is made of an outer layer of light-weight concrete blocks with pumice as aggregate. The core layer is perlite as loose insulation infill and the inside layer is made by compressed earth blocks produced by the university's team on campus. The windows are constructed as curtain walls with air-tight joints to the walls and gaskets, frames of UPVC with thermal breakers, and an argon-filled double glazing. The outer surface is equipped with a sun protective coating, which influences the radiation properties. The roof is a multi-layered construction with a loadbearing structure of reinforced concrete slab, an EPS insulation layer and a cover of sand and white cement tiles (Figure 3.1). The thermal material properties are taken from tables.

Case 2 “regulations” is a building according to the thermal performance requirements set in the Muscat Building Regulations from 1992 (Muscat Municipality 1992), which are still valid today. This document sets U-values to be $U = 0.741 \text{ W/m.K}$ for external walls and $U = 0.57 \text{ W/m.K}$ for the roof. However, no material specifications are made. To gain representative material data, an U-Value calculator conforming to the German norm DIN 4108 (DIN Deutsches Institut für Normung 2014) is used in an exemplary temperature setting. A suitable material configuration in accordance with the regulations is set concluding a support structure and an insulation layer. The properties from these materials are used for the simulation. The windows are not clearly specified in the regulations and therefore the same window properties as in the EcoHaus are used.



Figure 3.1: as built case - energy-efficient construction method of the GUTech EcoHaus



Figure 3.2: practice case – standard construction method for villas in Muscat

Case 3 “practice” is a building according to the standard building practice in Muscat, which for reasons of low-costs and non-enforcement of the above mentioned regulations, can be considered the standard. Here, the material specifications are assumed based on observation at the many construction sites in Muscat (see Figure 3.2). Houses are structurally based on a reinforced concrete frame of columns, beams and solid concrete slabs. The infills are made with a single layer of concrete hollow blocks, joined with cement mortar and rendered with a cement plaster on both sides. The blocks are partly built in semi-industrial plants and partly in “backyard factories”. Therefore, an even standard regarding their material properties cannot be assumed. However, it is reasonable to use data from industrial product catalogues and material property tables (Bobran and Bobran-Wittfoht 2008; Thomas Armstrong Ltd 2015). The commonly installed windows are single panes in aluminium frames. The heat conduction resistance of the pane is negligible against the convection on the surface. For the windows, a sun protective coating is assumed. Even though the standard construction system disregards the issue of thermal bridges and air leakages, this disadvantage is not further reflected in the model.

An overview of the resulting U^* -Values for all cases is given in Table 1.

Table 1: U^* -values in W/m^2K for house parts

<i>House part</i>	<i>Wall</i>	<i>Windows</i>	<i>Roof</i>
<i>Case 1 "as built"</i>	<i>0.14</i>	<i>2.07</i>	<i>0.15</i>
<i>Case 2 "regulations"</i>	<i>0.85</i>	<i>2.07</i>	<i>0.62</i>
<i>Case 3 "practice"</i>	<i>1.83</i>	<i>25.00</i>	<i>5.48</i>

3.2 Defining weather input data

For the analysis of the case study, periodic weather data in dependence on typical daily data in summer and winter season is created. Figure 3.3 shows the data exemplarily for 10 days in the summer. $T_{environment}$ is the environment temperature, E_{direct} the direct sun radiance and $E_{diffuse}$ the diffuse sun radiance. The temperature development is full periodic over 24 hours, while the radiance is half periodic during day time. The respective sun course is taken from (Hoffmann 2015), while the weather data is created in dependence on data from the company "Weather Analytics" (Weather Analytics LCC 2013).

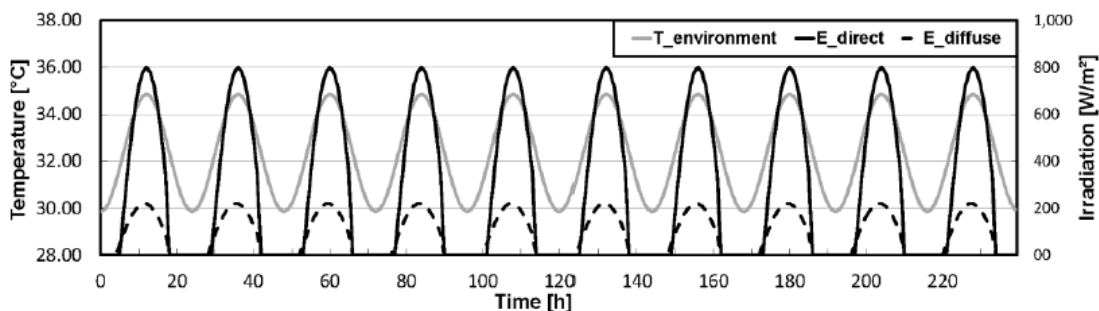


Figure 3.3: Weather data for the summer scenario

The environmental temperature for the summer scenario is between 30 °C and 35 °C. For the winter scenario, the same input signal is used with temperatures between 19 °C and 25 °C.

3.3 Examination

In a first step, the behaviour of the house is investigated without any cooling. This setting is called "stand-alone". To allow all examined temperatures to settle at a constant average value, 40 day periods are simulated. For the summer scenario an inner volume start temperature of 30°C is chosen, for the winter scenario it is 24 °C. The stand-alone setting is suitable to show the dullness (phase shift) and the relation of amplitudes between the air volume- and environment temperature. The air volume energy balance for this setting is analysed in detail afterwards to get a closer view on the temperature development and rate the envelope part's contribution. The balance is

$$c_{P,A} \cdot V_A \cdot \rho_A \cdot \frac{dT_A}{dt} = \dot{Q}_{Wall} + \dot{Q}_{Window,North} + \dot{Q}_{Window,South} + \dot{Q}_{Roof} + \dot{Q}_{Solid} \quad (3)$$

With $c_{p,A}$ as the heat capacity of the air, V_A as the volume of the air, ρ_A as the density of the air, T_A as the air temperature and with the heat fluxes on the right side. The respective index shows, which part of the house the air volume interacts with. In the analysis, the development during the 40 days of each flux will be examined.

Afterwards, the most interesting and significant value to compare the cases – the cooling load in the summer case – is examined. To implement this setting, the indoor temperature is limited at a certain comfort condition, but it can fall below this limit. This behaviour pictures the control of a simple air conditioning. Here, 24 °C and 20 °C are chosen as comfort conditions.

4. Discussion

4.1 Stand-alone temperature development

Figure 4.1 shows the temperature development for all three cases in the summer scenario with the air volume temperature of the as built case, the regulations case and the practice case. The environmental temperature is shown for comparison.

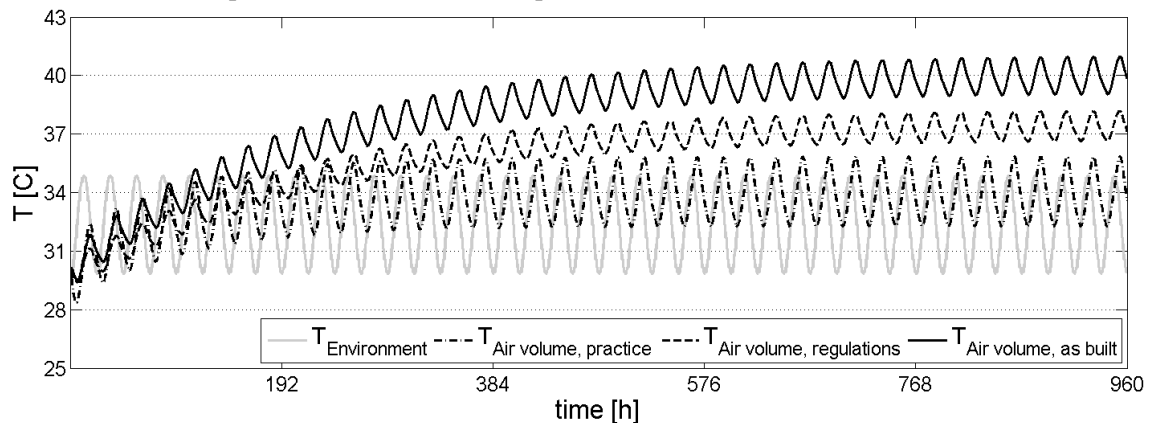


Figure 4.1: Air volume temperatures for summer scenario, stand-alone setting

The average air volume temperature settles above the environmental temperature in all cases, while the average temperature is maximal for the as built case. The relation of the amplitudes differs from the relations of the average temperatures. The regulations case shows the smallest amplitude, although the average temperature is in the middle of the three cases. The amplitudes of all simulated temperatures are significantly lower than the amplitude of the environmental temperature. The phase of the air volume temperature post-pulses approximately 5 hours behind the environmental temperature with nearly no differences in all cases. This phase shift is due to the high thermal mass with low thermal conductivities. The house's behaviour is the same for the winter scenario (Figure 4.2), but at a different temperature scale. The phase shift varies a bit and now post-pulses 2.5 to 4 hours behind the environmental temperature with a minor spreading. The air volume temperature is influenced by heat exchange with the inner surface of the envelope parts and with the solid volume. To see the relations between these flows, they are examined in Figure 4.3 to Figure 4.6 according to equation (3).

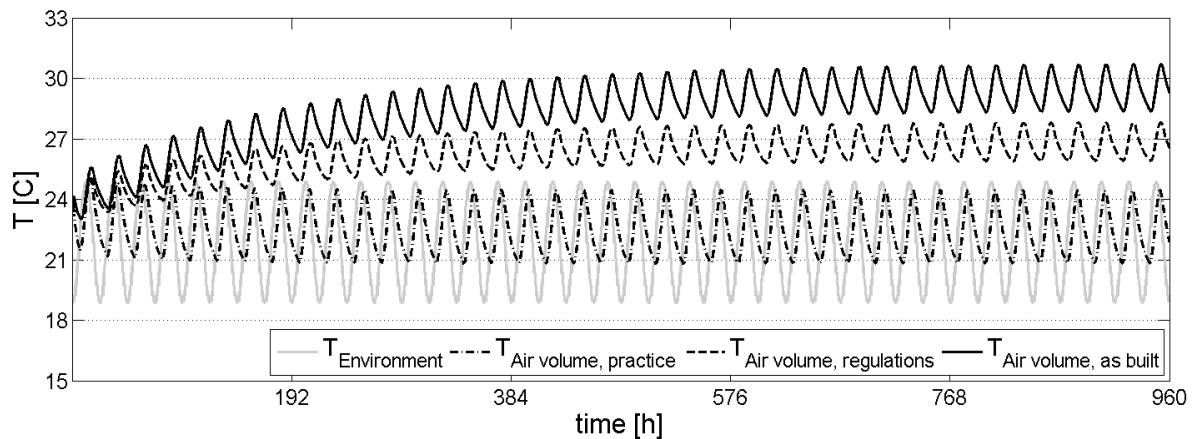


Figure 4.2: Air volume temperatures for winter scenario, stand-alone setting

4.2 Air volume energy balance

The contribution of the respective inner surface in the air volume energy balance is a result of the air volume temperature and the surface temperature. This one is influenced by heat that conducts through the wall and radiation that is transmitted through the windows. The radiation heats the inner walls and the solid volume, but not the ceiling. Heat conduction occurs for the wall, the roof and the windows.

The convective flow from the north side window to the air volume is drawn in Figure 4.3 for the practice case. The large area with the high heat conduction coefficient is not exposed to direct sun light due to the orientation and the air volume temperature is above the environment temperature. Therefore, this window mostly acts as a heat sink with amplitude up to -1400 W. The south side windows show a similar behaviour with minor amplitude of up to -300 W (Figure 4.4). These windows are exposed to direct sunlight only for a few hours a day.

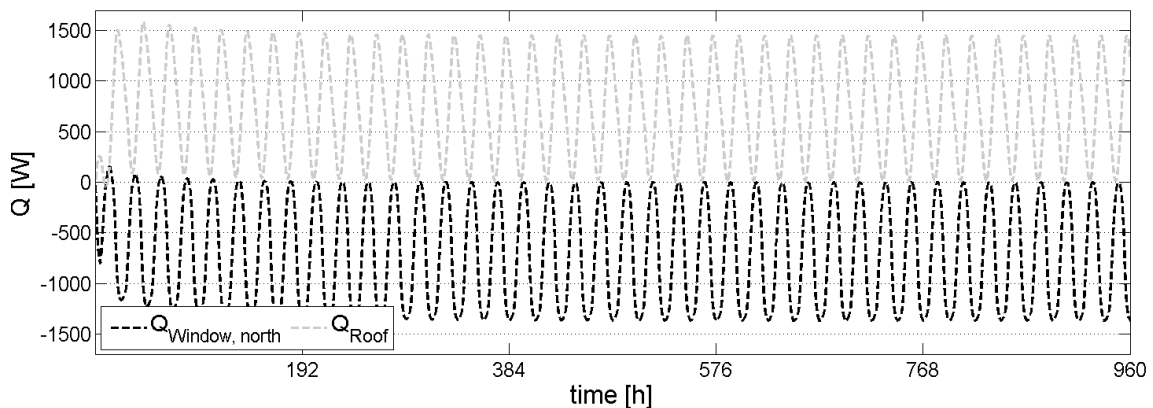


Figure 4.3: Heat fluxes in air volume energy balance for summer scenario, practice case, part 1

The heat flux through the roof is drawn in Figure 4.3. It is phase shifted by approximately 10 hours in relation to the window flux and the amplitude reaches the same order of magnitude – around 1500 W. Due to the constant sun exposition of the outer surface during the day and the resulting heat conduction, the heat flux is positive.

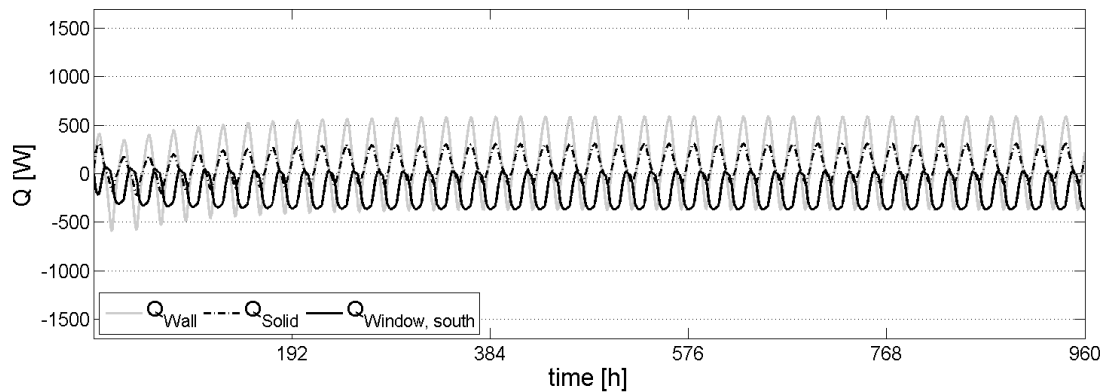


Figure 4.4: Heat fluxes in air volume energy balance for summer scenario, practice case, part 2

The heat exchange with the solid volume (Figure 4.4) is mostly positive at around 1/3 of the north side window- and roof flux amplitude. The solid volume is heated only by the transmitted radiation. As the phase is the same for the solid volume and the wall (between the roof and the windows flux), the transmitted radiation influence on the wall flux must be dominant against the conduction in the wall, although the outer surface of the wall is exposed to the sun several hours a day. This is due to the very high insulation.

For the regulations and as built case (Figure 4.5 and Figure 4.6, please notice different scale than in Figure 4.4), the phase correlations are generally the same. The roof and north side window fluxes are significantly lower and in the order of the other fluxes. This is in accord with Table 1, since the U^* -values are in another order of magnitude. In general, the air volume temperature above the environment temperature in all cases is an indicator for the dominance of the transmitted irradiation against the convection.

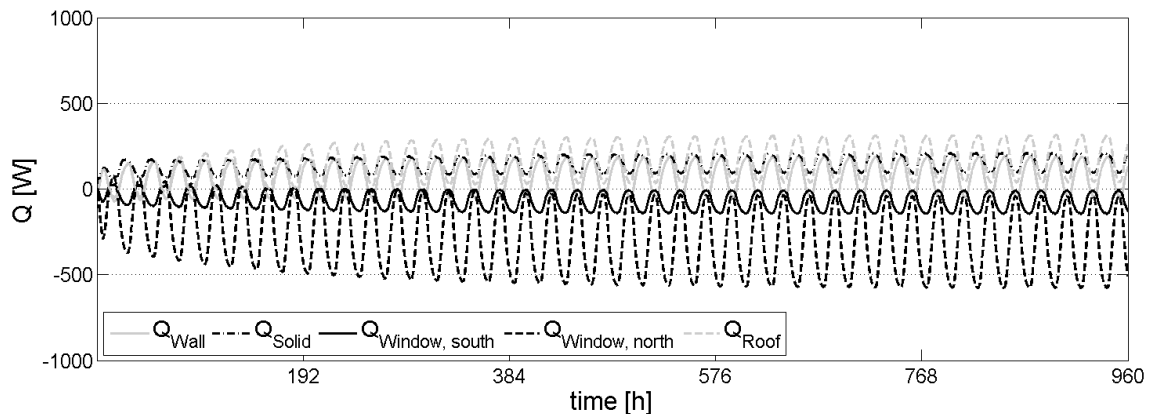


Figure 4.5: Heat fluxes in air volume energy balance for summer scenario, regulations case

The reason for the amplitude correlation in the temperature development (Figure 4.1) is in the phase shift of 10 hours between window and roof flux, which is nearly half a period. Due to this, effacement occurs and the amplitude of the temperature gets lowered. The higher conduction ability of the roof allows the heat during the day to escape better.

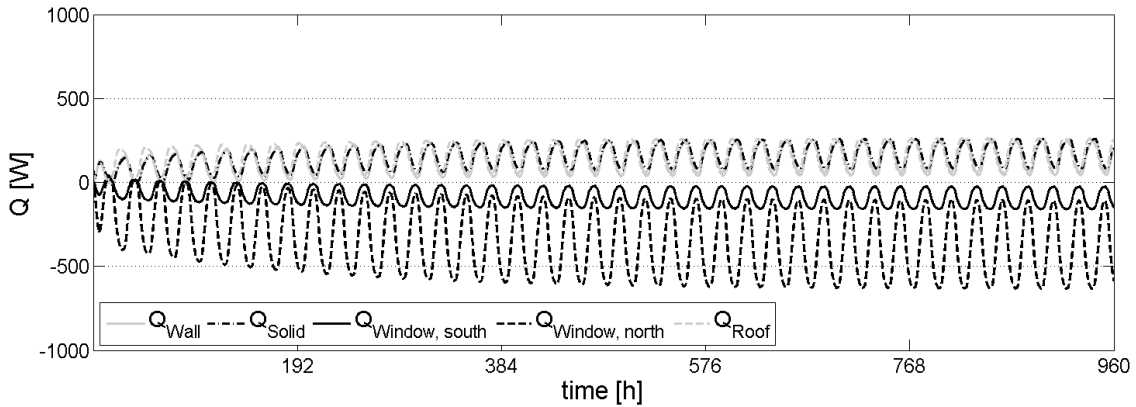


Figure 4.6: Heat fluxes in air volume energy balance for summer scenario, as built case

Overall, the house isolation holds the energy that is yielded by the radiation, from conducting to the cooler environment. The air volume is “decoupled” from the environment. This leads to a high dullness of the average settle temperature. Due to the different sun exposition of the parts, the contribution in the energy balance is not always in the relation indicated by the U^* -values. Just these results get visible by the time dynamic modeling approach exclusively.

4.3 Cooling load

By the analysis of the cooling load and accordingly the summarised cooling energy demand for the 40 day period, the advantages of the EcoHaus can be quantified. Figure 4.7 pictures the load over the time for the summer scenario for all three cases normalised to the living area of 210 m.. Both, the amplitudes and the settle averages, are in accord with the stand-alone setting. The results for the summarized cooling energy demand are shown in Table 2 for two set temperatures. The advantage of the EcoHaus is obvious with a saving of up to 30 % in comparison with the regulations case and up to 60 % in comparison with the practice case. In reality, the practice case is supposed to show a significantly higher cooling load, since air leakages are not considered in the model and in this benchmark, some passive strategies (round shape and north-orientation) are implemented in all cases due to the same geometry.

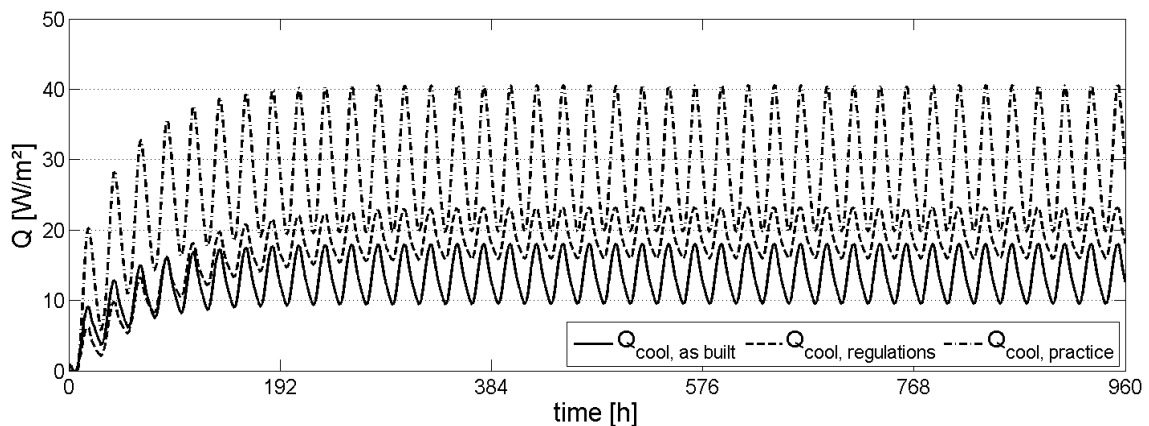


Figure 4.7: Cooling loads for summer scenario with set temperature 297 K

During the winter period a cooling by natural ventilation is possible. Therefore, the winter scenario has no relevance for the cooling load considerations.

Table 2: Accumulated cooling energy demand for 40 days in kWh for the summer scenario

<i>Cooling energy</i> <i>Set temperature</i>	<i>as build</i>	<i>regulations</i>	<i>practice</i>
<i>24 °C</i>	<i>2600</i>	<i>3550</i>	<i>5340</i>
<i>20 °C</i>	<i>3240</i>	<i>4660</i>	<i>8120</i>

5. Conclusions and Outlook

The benchmarking for the summer period shows that – based on model calculations with a fixed geometry – the EcoHaus saves 30 % of the cooling energy demand in comparison with a building built according to the Muscat Municipality regulations. Further, it saves 60 % of the cooling energy demand in comparison with a building built according to the standard construction methods.

In preliminary considerations, the EcoHaus is examined in a stand-alone setting, where the thermal properties of the house are investigated. The high insulation decouples the inside of the house from the environment and promotes the radiation influence on the temperature but also damps the amplitude in comparison with the environment temperature. The resulting high dullness can be advantageous. For example, the temperature stays stable enough during the night without uncomfortable cooling.

All parts of the envelope participate differently in the air volume energy balance. The period of time in each day, in which they are exposed to the sun and the insulation differ strongly. The main window front is oriented to the north side, which means that it is never exposed to direct sun radiation. Therefore, heat entrance or transmission of direct radiation at the thermal weak point of the house is avoided. This design enables the house to be equipped with a window of huge size without increasing the cooling load too much. As a result, the rooms are sufficiently lit by daylight without compromising on energy efficiency. For a residential purpose in the Omani cultural context, more privacy would be required and shades would need to be installed.

The comparisons show the high impact of the passive design strategy to construct a highly insulated, protective envelope. Other passive strategies like the compact volume are included in the model with the geometry for all examined cases. In result, the cooling load is at a low to average level in all cases, showing the advantage of these strategies. The geometry differs significantly from common residential houses. A comparison with the actually built design of single-family villas in Muscat – that do not consider any passive strategies – would show the advantages of the EcoHaus design even more. Due to the modularity of the simulation, this is possible, also for new house designs, but it requires a new superordinate code.

The benchmarking extracts the cooling energy demand quantitatively, but does not address the question of how efficiently it can be provided. Here, the EcoHaus's cooling system - a combination of a hydronic, radiant cooling device and energy recovery ventilation is much more efficient than the generally employed AC-split-unit. Furthermore, the installed cooling system is

seen as a major contribution to increasing the living comfort since the air-velocity is low and with minimal audible sounds.

The study shows that significant savings in the energy consumption of buildings in Muscat and comparable hot and humid climates can be achieved through better designs and better construction systems. However, the problem of achieving better performing buildings not only lies in the knowledge generation about the best solutions, but also in the knowledge transfer to get these solutions implemented. The EcoHaus project of the GUTech in Oman is an example that through the involvement of students into research and practice, both elements, knowledge generation and transfer to the next generation in the country, can be combined successfully.

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BIM for Infrastructure Sustainability in Developing Countries: the case of Ethiopia

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Abstract

Investment in infrastructure in developing countries is essential for poverty reduction and it positively and significantly correlates to their economic growth. As infrastructure development involves consumption of considerable natural and capital resource and as it has long term impact on socio-culture of societies, it should be sustainable both in terms of delivery and service. Achieving sustainable infrastructure entails concerted considerations all the way from inception to demolition stages. In contrary to the fact that the issue of sustainability is in vogue, its implementation in infrastructure development in developing countries like Ethiopia is still at its infancy. In the traditional design and delivery approach where sustainability issues are not adequately addressed, resulting infrastructure becomes fragmented that is highly unsustainable and vulnerable. Due to presence of huge input and complex process in sustainable infrastructure design and delivery, the need for innovative information based interventions like Building Information Modelling (BIM) is inevitable. While implementation of BIM in the developed world is very encouraging, its application in the developing countries, especially in the area of infrastructure is very much limited. In this regard, the role higher educational institutes play in the diffusion of this technology into the industry is vital. The objective of this study is to explore the preparedness of Architecture, Engineering and Construction Management (AEC) undergraduate students to use BIM in the construction industry upon their graduation. Literature review and a semi-structured questionnaire were used to establish the conceptual background and acquire empirical data respectively. 95 Architecture, Civil Engineering and Construction Technology and Management graduating class students studying at the prominent state owned university in Ethiopia were included in the study. The response rate was 95% and the results of the study indicated that awareness and preparedness of the graduating students to use BIM in the Ethiopian AEC industry is very low. This is especially true to Civil Engineering students who are responsible to design and manage construction of majority of infrastructure projects in the country. Respondents indicated unpreparedness of the AEC industry and absence of appropriate software and work stations as the two major challenges to offer BIM at their university

Keywords: BIM, infrastructure, Sustainability, higher education, Developing Countries

1. Introduction

Investment in infrastructure in developing countries is essential for poverty reduction (Fay, et al., 2011) and it positively and significantly correlates to economic growth. According to the World Bank report there is a huge gap in infrastructure provision which is estimated at \$1 trillion in low- and middle income countries, and the demand continues to grow as countries develop (The World Bank Group, 2008). The fact that infrastructure facilities last long signifies the need to make them sustainable by designing and constructing them to accommodate the several requirements that would emerge in due course of their lifetime. These requirements include social, economic, financial, and environmental considerations.

Achieving sustainable infrastructure entails concerted considerations all the way from inception to demolition stages. In contrary to the fact that the issue of sustainability is in vogue, its implementation in infrastructure development in developing countries like Ethiopia is still at its infancy. In the traditional design and delivery approach where sustainability is not adequately considered, resulting infrastructure becomes fragmented that is highly unsustainable and vulnerable (Sarte, 2010).

Due to presence of huge input and complex process in sustainable infrastructure design and delivery, the need for innovative information based interventions like BIM (Building Information Modelling) is inevitable. While implementation of BIM in the developed world is very encouraging, its application in the developing countries, especially in the area of infrastructure is very much limited. It is argued that lack of skilled and knowledgeable professionals is one of the bottlenecks for successful implementation of the technology. The role higher educational institutes play in regards to breeding the new BIM literate generation is vital. This signifies the need to assess the current trend in higher educational institutions in regards to training and capacitating Architectural, Engineering and Construction Management students in the developing countries like Ethiopia.

This study attempts to explain the role of BIM in sustainable infrastructure design and delivery and it investigates the preparedness of Architecture, Civil Engineering and Construction Technology and Management undergraduate students to implement BIM in the construction industry to attain sustainable infrastructure in Ethiopia. The research tried to identify the possible challenges faced by higher education institute in Ethiopia to offer BIM in these programs.

The study is limited to adoption of BIM in Ethiopia with a particular emphasis on Architecture, Civil engineering and Construction Technology and Management final year students. The findings are expected to be of assistance to Ethiopia and other developing countries in the design and delivery of sustainable infrastructure through implementation of BIM. It contributes to the body of knowledge in the area of sustainable infrastructure design and delivery in developing countries.

This article has six sections. Sections two and three discuss about sustainable infrastructure and BIM correspondingly. Sections four and five present the research methodology and survey results. Concluding remarks and recommendations are stipulated under section six.

2. Sustainable Infrastructure

2.1 Background

In the broader context the term infrastructure may refer to either "soft" or "hard" infrastructure. Hard infrastructure entails provision of physical structures for basic services including energy, water supply, sewerage, transportation, waste removal, sanitation, communication, health and education. While hard infrastructure is about provision of physical assets, soft infrastructure is about development of skill and knowledge and access to appropriate services (Casey, 2005).

Infrastructure can also be categorized as economic and social infrastructure where economic infrastructure is part of an economy's capital stock used to facilitate economic production. Structures including power utilities, piped gas, telecommunication, roads, drainage, railways, runways and seaport are typical examples of economic infrastructure. Social infrastructure on the other hand facilitates investment in human capital with a result of improving workforce productivity. Health, education, safety and recreation service facilities are typical examples of social infrastructure (UN-HABITAT, 2011). This study is limited to hard and economic infrastructure.

According to the World Bank report (Fay, et al., 2011) despite the fact that 10 percent increase in infrastructure investment contributes to one percent growth in GDP, there is a gap in infrastructure provision which is estimated at USD 1 trillion in low- and middle-income countries, and the demand continues to grow as countries develop. While developing countries are engaged in massive construction undertakings to curb their infrastructure deficiencies, only limited progress has been made so far (Calderon & Serven, 2004).

African countries, especially, sub Saharan Africa countries trail behind other regions in terms of infrastructure delivery and quality. This has becoming an impediment to their economic development and a major constraint on poverty reduction. To fill the infrastructure gap, an estimated USD 93 billion, which is about 15% of GDP a year investment in infrastructure is needed in Africa (UN-HABITAT, 2011). Infrastructure access gap looms large in the developing world where an estimated 748 million people live without access to safe water, 1.2 billion without electricity, 2.8 billion still cook their food with solid fuel such as wood, 1 billion people live more than two kilometres away from an all-weather road, 2.5 billion without sanitation, and more than 1 billion without access to telephone services (Lin, 2005; Todaro & Smith, 2012; Fay, et al., 2011).

Ethiopia is a country in East Africa with one of the fastest growing economies in the world and having an average growth rate of above 10% for the last decade where this momentum is expected to continue at a rapid pace over the next five years (AfDB; OECD; UNDP, 2014). With a population of more than 90 million it is the second most populous country in Africa following Nigeria.

The Global Competitiveness Report 2014-2015 (World Economic Forum, 2014), positioned Ethiopia 125th out of the total 144 countries considered in the survey in terms of overall quality of infrastructure where the report highlighted the need for significant improvement to enhance competitiveness of the country's competitiveness in the global market.

According to the United Nations report (United Nations Human Settlements Programme, 2011), only less than 20 percent of the Ethiopian population has access to any modern infrastructure. Surveys indicated that infrastructure constraints are responsible for an estimated 50 percent of the productivity handicap faced by Ethiopian firms (Foster & Morella, 2011).

In the course of time, infrastructure and utilities age and will require substantial maintenance and retrofitting if not demolished. Martland (2012) argues that social and environmental impacts of infrastructure systems likely become more apparent over their life time suggesting the need to consideration of sustainability aspect starting from the very early stage of the project design. According to Kibert (2013), the built environment has direct, complex, and long-lasting impact on the planet than any other human venture.

According to a report by CIB (1999) sustainable construction entails sectorial contribution made by the AEC industry in the areas of environmental, social, ecological and cultural aspects in the effort to achieve sustainable development. Sustainable construction is defined by Agenda 21 for Sustainable Construction in Developing Countries discussion document as follows (CIB & UNEP-IETC, 2002): "Sustainable construction means that the principles of sustainable development are applied to the comprehensive construction cycle from the extraction and beneficiation of raw materials, through the planning, design and construction of buildings and infrastructure, until their final deconstruction and management of the resultant waste." (pp 6)

Williams (2007) described the sustainability design process as integration of design into the ecology of the place which is the flow of materials and energy residing in the community. Compared to conventional design, sustainable design needs additional criteria and items (Azapagic & Collett, 2006). To implement sustainability on real projects, it needs to understand sustainable practices and then choose appropriate measures to facilitate sustainability realization (Chang & Tsai, 2015). As a sustainable approach new options to substitute the services that were provided by the old infrastructure need to be looked into (Williams, 2007). The emergence of BIM which is an important milestone in the AEC(Architecture, Engineering and Construction) industry affects the traditional approaches to project design and collaboration (Kibert, 2013). The next section describes the concept and benefits of BIM.

3. Building Information Modelling (BIM)

3.1 Background

Yan and Damian (2008) described BIM as powerful software tools used in the construction industry offering a considerable benefits throughout life cycle of a building including design, construction and facility management. BIM is a fairly new innovation in the construction industry changing the conventional way of designing, constructing, and operating buildings and infrastructure. The aim of BIM approach is to be able to digitally view and access information about the construction project from a single-source model (Krygiel & Nies, 2008). Unlike 2D drawings where drawings merely show a representation of the final object, BIM models have simulation capabilities. High level of accuracy and design efficiency can also be achieved by using BIM (Krygiel & Nies, 2008).

Building Information Modelling (BIM) is a relatively new technology and has been in use in many countries where several researches and surveys were made to assess level of adoption of the technology (Jung & Lee, 2015; Hussain & Choudhry, 2013; Abubakar, et al., 2014; Langar & Pearce, 2014; Wong, et al., 2010; Mohannadi, et al., 2013; Rogers, et al., 2015). The AEC industry will be able to utilise the full potentials of BIM only if it is widely endorsed by the stakeholders and adopted throughout the industry.

3.2 BIM Implementation and Barriers

In contrary to the fact that BIM offers immense benefit to the construction industry, its adoption is impeded by several barriers. Liu, et al (2010) conducted a study to identify factors influencing adoption of building information modelling in the AEC industry and indicated that maintaining staff with sufficient knowledge to perform facility management using BIM is one of the limitations faced by companies to adopt BIM. Hartmann and Fischer (Hartmann & Fischer, 2008) indicated the scarcity of BIM conversant practitioners as one of the major hindrances for its widespread adoption.

Adoption of new technologies requires identification of potential barriers and key effective implementation strategies in order to ensure successful diffusion and implementation of the technologies. Research in UK indicated that lack of BIM knowledge and skills raised concern and delay in the uses of BIM in the UK (Young, et al., 2008). According to Fox and Hietanen (2007) lack of highly skilled cross trained staff with both construction and IT skill is one of the barriers hindering realization of BIM benefits.

3.3 BIM in Higher Education Institutes

The introduction of AutoCAD about thirty years ago paved a way to computer assisted design in the construction industry. Currently, computer-based design courses are streamlined and given in several undergraduate courses specially in developed countries. According to Dean (2007) BIM should be taught in educational institutions as graduates with BIM literate graduates have more advantage over BIM illiterate graduates. Fox and Hietanen (2007) highlighted that students and graduates with BIM knowledge and proficiency play an important role in the use of BIM within their organizations. A research in the UK recommends rearrangement of construction courses at universities to better equip students to meet the growing demand of the construction industry (Bataw, et al., 2015).

Construction education should keep itself updated with new innovations and industry. According to Deutsch (2011) BIM should be integrated into Architecture, Construction and Engineering programs. Ahbab, et al. (2013) stated that educational institutions should produce BIM enabled professionals for adoption of BIM in the construction industry. Cooksey and Schiff (2012) recommended that students should be able to acquire knowledge about the capabilities of BIM and effective use of the tool before they join the profession.

4. BIM for Sustainable Infrastructure

The AEC industry is becoming more and more complex and requiring more specialization. Specialization in turn opens a door for fragmentation in the industry and contributes to the decline in efficiency of the industry compared to other industries (Krygiel & Nies, 2008). In line with complexity of building and infrastructure systems, the presence of plentiful design requirements and the complex interrelationship between these requirements suggest the need for an integrated approach to design, construction and operation of buildings and infrastructure.

The construction industry is currently under immense pressure globally in terms of timely delivery, consideration of sustainable practice, value for money, etc. Several attempts were made to improve the situation through devising alternative procurement methods, introducing better innovative construction technologies and innovative processes including Computer Aided Design (Abubakar, et al., 2014) .

Vallero and Braiser (2008) indicated that BIM offers a great potential for sustainable design through increased teamwork and integration across different disciplines. BIM helps to test "what if" scenarios at the early design stage of projects and enable designers analyse several options which is an essential element of sustainable infrastructure design (Vallero & Braiser, 2008). Crotty (2012) stresses that safety, soundness and sustainability concerns of the public will be accommodated in software programs in a BIM-based industry. Malina (2013) suggests that BIM can be considered as a more sustainable and cost effective tool to deliver sustainable buildings.

A holistic design which is an approach for sustainability of the AEC industry calls for collaboration of different professional including architects, engineers and urban planners where these professional share information and tools supporting this approach need to emerge (Shen, et al., 2009). BIM enables designers to iterate and analyse sustainable design options faster than in a more traditional process (Krygiel & Vandezande, 2014).

One of the emerging project delivery methods called Integrated Project Delivery (IPD) is claimed to have many of the attributes of construction delivery systems very much compatible with Energy and Environment certification systems. According to Kibert (2013) BIM is instrumental in the successful implementation of IPD by providing the possibility for good collaboration on construction projects.

A study has indicated that BIM is a very effective tool to teach students concepts of building sustainability. It is argued that while sustainable building design and construction is being gradually integrated into construction curricula in higher educational institutes due to the complex nature of the subject, its instruction and learning is a challenge (Shen, et al., 2012).

5. Methodology

The research methodology employed includes literature review in relation to the role of higher educational institutes in facilitating BIM adoption rate of the construction industry. The review also

used to identify the role of construction education institution in adoption of the technology in the AEC industry. Following the literature review, a semi-structured questionnaire was developed and a survey was conducted among final year Architecture, Civil Engineering, and Construction Technology and Management undergraduate students to assess their acquaintance with BIM and their perception about its benefits and practicability. The survey is designed to explore Architecture, Civil Engineering and Construction Technology and Management students level of preparedness to use BIM upon their graduation. It further aims to assess students willingness to learn BIM if they are given the opportunity.

The survey was conducted at the Addis Ababa University, the largest and oldest university in Ethiopia. The University is located in Addis Ababa, the capital city of Ethiopia and it is a flagship state owned educational institute. It was the first institute to start all the three undergraduate programs namely Architecture, Civil Engineering and Construction Technology and Management in the country. In 1955 a four year Civil Engineering program was introduced followed by Building engineering program in 1958. Lately a bachelors program in Construction Management and Technology program was opened in 2002. The university is considered as a trend setter in the country and it is fair to assume that it is a very good indicator of the situation in educational institutes in Ethiopia especially in terms of AEC studies. As graduates of the three field of studies involve in the design, construction and facilities management of infrastructure project the study focused only on these programs.

The research questionnaire has three sections: it begins with background questions followed by structured questions asking students to give their opinion about their competence and orientation towards BIM. The second section also includes a question asking students to prioritize the possible challenges of offering BIM courses in their respective programs. The last section has semi-structured questions dealing with students awareness and the types of BIM software programs they are acquainted with.

6. Results and Discussion

This next sections presents results of the survey and discusses on the findings.

The questionnaire survey was conducted at the end of 2015. The data analysis included descriptive analysis and comparative statistics.

A total of 100 questionnaires were distributed to a randomly selected students and 95 completed questionnaires were returned which is a 95% response rate. Out of the total respondents 33.7% (32) of them are female and the remaining 66.3% (63) of them are male. According to their field of studies students studying Architecture and Civil Engineering constitute 31.6% each and the remaining 36.8 % of the respondents are students from Construction Technology and Management. In the researchers opinion, the field of study composition of the respondents is a fair representation of the professionals involved in infrastructure planning, design, construction and facilities management. All respondents are final year students and are expected to join the AEC industry within one to five months time depending on their program structure.

Table 1 depicts that all architecture students are aware of BIM but only 33.7 % of them are aware of its benefits. 31.8% of architecture students said they have used BIM during their studies and only 27.9% of them indicated they have taken a course on BIM on campus. 23.2% of Civil Engineering and 18.3% of Construction Technology and Management students said they have never heard about BIM. As to awareness of BIM and its benefits, 66.3% of the respondents responded positively out of which half of them were Architecture students. In all cases Architecture students have shown better awareness and level of competence about BIM. However, involvement of Architects in Infrastructure design and construction in Ethiopia is limited when compared to the other two field of studies.

Table 1: Respondents awareness about BIM

<i>Questions Field of Study</i>	<i>Never heard about BIM</i>	<i>Aware of BIM and its benefits</i>	<i>Used BIM on campus</i>	<i>Taken a course on BIM on campus</i>
<i>Architecture</i>	-	33.7%	31.8%	27.9%
<i>Civil Engineering</i>	23.2%	13.5%	10.2%	10.1%
<i>Construction Technology and Management</i>	18.3%	19.1%	14.8%	3.8%
<i>Total</i>	41.5%	66.3%	56.8%	41.8%

As shown in Table 2 the respondents indicated unpreparedness of the construction industry and absence of adequate and appropriate software and work stations as the two major challenges to offer BIM at the institute under consideration.

Table 2: Challenges of offering BIM at higher education institute as rated by respondents

<i>Field of study Challenges</i>	<i>Architecture</i>	<i>Civil Engineering</i>	<i>Construction Technology & Management</i>	<i>Cumulative</i>
<i>Unpreparedness of the Ethiopian construction industry to widely implement BIM</i>	4.03	3.84	4.03	3.97
<i>Absence of adequate and appropriate software and workstations</i>	3.67	3.35	3.86	3.61
<i>Lack of awareness of the institute management and academic staff</i>	3.10	3.41	3.79	3.42
<i>Lack of well trained staff</i>	3.43	3.32	3.24	3.33

Note : 1 = Strongly disagree; 2=disagree; 3=neutral; 4=agree and 5=strongly agree

86% of the respondents showed a very high interest to learn about BIM and 93% of them indicated that BIM would be very instrumental to improve the AEC industry in Ethiopia. Of the total students who responded that they are aware about the benefits of BIM, 52% of them failed to provide correct answers to the questions asking about benefits of BIM. This implies that the awareness of the students about BIM could be even below than the figures indicated in Table 1.

7. Conclusions

Investment in infrastructure is key for economic development especially for developing countries like Ethiopia. As infrastructure development involves consumption of a considerable natural and capital resource and as it has long term impact on socio-culture of societies, infrastructures should be sustainable both in terms of delivery and service. One of the innovative tools to help the AEC industry deliver sustainable infrastructure is BIM. While developed countries are in a better level in making use of BIM, developing countries are still struggling to benefit the great advantages of the technology. The role higher educational institutes play in the diffusion of this technology into the industry is vital.

Results of this study indicated that awareness and preparedness of AEC graduating students to use BIM in the Ethiopian AEC industry is very low. This is especially true with Civil Engineering graduating students who are responsible to design and manage construction of majority of infrastructure projects in the country. According to the study Architecture students have better acquaintance and competence in using the program showing the prospects that Civil Engineering and Construction Technology and Management program can also enable their students gain the knowledge and skill their students need.

To pave a way to make use of the vast potentials of BIM, educational institutes in Ethiopia should go extra mile to equip their students with this technology. Teaching students BIM at a university level before they join the industry should be reasonably less costly and it plays a vital role to help the industry move towards wide implementation of BIM for delivery of sustainable infrastructure.

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Colonias Building Information Modelling Toolkit (CBT): A Process to Guide Policy Decisions

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Abstract

Colonias are substandard and low-income self-help housing developments along north of Mexico - US border. There has been an increasing concern over sustainable development and energy efficient design techniques which addresses both new and existing housing. However, there is a need for housing policy focuses on informal self-built low-income housing context (Sullivan and Ward 2012). In this paper, we discussed the potential way of integrating BIM technology to address sustainable improvements in informal settlements housing policy.

This paper builds on our previous research that proposed a new tool, Colonias BIM Toolkit (CBT) to model and assesses the incremental changes over time and the building performance (Yenerim 2014). To explore this goal, we have investigated the possible use of CBT based home models and energy estimates for policy stand point. Our provision was to guide residents towards better individual decisions on design of their homes by utilizing this tool. The proposed technique can be applied to any informal settlements around the world. However, as a matter of convenience, the proposed technique was tested on Colonias in Laredo, Texas. We proposed a technique to devise a Building Information Modeling toolkit to model informal settlements and a multiple analyses to produce a probabilistic estimate of energy consumption. We argue its benefits through one colonias home in Laredo, Texas which has been built in three stages over three years.

Our hypothesis was that BIMs of homes and communities can be stored as a database to be used by policy makers and researchers on investigating their growth pattern and to set up regulations on rehabilitation of these structures. If policy makers have data on existing construction techniques and materials of homes and a 3-dimensional visual data on the form of homes, policy makers can monitor and control the form of houses and the growth of the settlements. Moreover, having estimate of existing energy consumption of homes and communities can enable policy makers to set up regulations and rules for more sustainable home design and rehabilitation of existing ones.

Keywords: Informal housing, colonias, Colonias BIM Toolkit, Sustainable Cost Efficient Housing, policymaking

1. Introduction

The aim of our research is to determine basic aspects of the practicality of a model-based approach to guide policy decisions about informal settlements in terms of energy conservation. We speculate that modelling an entire community of homes in an informal settlement and simulation of homes could provide insights about energy consumption, visual qualities, and other considerations, enabling analysts to examine multiple scenarios of how the community might change. Policy-makers could use the growth patterns and consumption patterns to plan regulation and interventions to achieve improved outcomes and to help residents to build more formal homes. Our study has shown the feasibility of using Building Information Modelling (BIM) and energy simulation to support analysis and prediction of the performance of homes that can be aggregated to show the performance of communities. To predict the performance of homes, we have determined the probable performance of homes by utilized parametric variation and simulation. Our models have not yet been calibrated; future work could examine the predicted energy consumption against the actual consumption. We believe that our process can be used for informal settlements around the world to estimate current and future energy use and guide development of policy.

In a previous study, we devised a toolkit (the Colonias BIM Toolkit, or CBT) from BIM technology to enable rapid modelling and simulation of the homes that make up a community (Yenerim 2014). Our process was to collect physical data pertaining to house footprint, materials and construction techniques by using a face-to-face interview with residents and in-depth on-site home inspection. The CBT includes a library of building components and systems observed in a test sample of homes in colonias. Our study used colonias along the border between Texas and Mexico as an example of informal settlements.

In this paper we present the use of the toolkit to model a single house and then perform a parametric study of energy simulations to determine a range of possible energy performance.

2. Informal settlements and Building Information Modelling

One of the major challenges is the unpredicted sprawl of informal settlements and their potentially deleterious impacts upon environments and explosive growth in consumption (UN-Habitat 2003). Informal settlements are substandard low-income housing development for people who cannot afford formal housing structures. They occur in most developing and developed countries (UN-Habitat 2003; Amis 2002; Burdett and Sudjic 2007; Davis 2006; Turner 1977). According to literature, there are several methods for upgrading informal settlements : relocation, resettlement, or self-help in-situ construction (Huchzermeyer and Karam 2006). Self-help improvement through participation of residents is frequently cited as the most successful way of rehabilitation of these settlements.

Informal settlements can consume high levels of energy in comparison to formal settlements with building codes and construction standards (UN-Habitat 2008). However, an estimated energy use of existing structures or communities may be difficult to determine due to lack of

knowledge of existing construction methods and insulation values. There is a lack of knowledge about the construction techniques and materials about these structures. Moreover, estimating the energy consumption of communities could enable policy makers to set up regulations and legislations on energy efficient home improvements and improve building code regulations for these structures. It could also be possible to use technology to assist field agents in advising residents how best to upgrade their homes in self-help projects.

For a test case, we selected the colonias in Texas as having many characteristics in common with informal settlements in other parts of the world. As a substandard housing development, most of these structures do not meet building codes (Bradshaw et al. 2005; Donelson and Esparza 2010; HUD 2008; Parcher and Humberson 2009; Ward et al. 2010). As a result, colonias residents pay more for their energy bills per square footage than an average U.S. resident pays (Gharaibeh et al. 2009; Giusti and Estevez 2011; Gharaibeh et al. 2009; Ward et al. 2010).

Three main housing types within the colonias have been identified: self-help homes, single or double wide manufactured homes and modular homes, and recreational vehicles (Sullivan and Ward 2012). Many homes combine all three of these. The self-help housing process results in a variation in construction materials: wood, concrete blocks, cardboard, and even dilapidated trailers (McKenzie 2002; SOS 2012). A common scenario is that a resident chooses a lot in colonias and lives in a temporary structure such as a trailer or camper. The residents build their homes by themselves or with the help of other residents and family members. Availability of money and materials is one of the major determinants for the how long the construction process would take place. Moreover, according to their changing needs such as expansion of their families, residents continue to add more rooms and expand their homes.

Because of being built over an extended period of time using materials that are ready at hand at the moment and being constructed outside of regulatory oversight by unskilled or semi-skilled labour, colonias homes show a great variety in terms of the quality of the structure. On one hand, some homes are built by reputable developers and homebuilders, while other residents live in make-shift structures, repurposed farm buildings and dilapidated trailers (Sullivan and Ward 2012; Ward et al. 2011). To that extent, although there are several studies focused on colonias homes and their materials, there are still unknown parameters about these houses.

Contemporary advanced computer software could provide those working to improve homes in the colonias with new and more effective methods to effect change and establish policy. Building Information Modelling (BIM) is an object-oriented modelling technology that is becoming widely accepted in building industry, replacing Computer-Aided Design (CAD) technology (Eastman et al. 2008). BIM integrates graphical and non-graphical information and enables users to control them through established parameters (Eastman et al. 2008). Furthermore, BIM facilitates the conduct of simulations that can predict the performance of building designs. In our study, we selected BIM technology to take advantage of its several capabilities such as 3-dimensional visualization of a structure, ability to document data, library of components and system families, parametric modelling capability, and simulation tools.

Our research is focused on exploring the benefits of the use of software, expressed as the CBT, to estimate the existing energy consumption of homes in the colonias and monitor the growth of the communities to aid in development of policy. Our approach is intended to model existing homes and communities rapidly, and to estimate current and future energy consumption of informal communities. By collecting models, it will be possible to build an extensive database which can be helpful to monitor the increase in energy use due to the growth of these settlements. We discuss the potential benefits this toolkit for policy makers to establish guidelines on low-cost energy efficient design and construction strategies for residents and to improve the building codes. We argue that policy makers can provide assistance in more sustainable energy efficient improvements in design and construction methods according to the adopted architectural patterns by residents.

3. CBT Methodology: A Process to Guide Policy Decisions

Modelling and simulating homes in informal settlements is difficult due to the lack of data about construction and other factors that affect energy performance. We have used parametric modelling and simulation, and statistical methods to determine potential likely range of energy performance of a home. We have tested 20 scenarios on unknown parameters of the homes.

We used Autodesk Revit 2014 for modelling homes and Autodesk Green Building Studio (GBS) to perform energy simulation. Several factors have an impact on energy use of buildings: building components, such as floors, walls, ceilings, roof, and window and doors, air movement through the envelope of the building, heating, cooling and lighting systems, residents, and outside factors such as; wind, sun, temperature, and humidity. When it comes to informal settlements, it is even more difficult to predict these variables because these structures are self-built substandard construction which, most of the time, do not meet building codes. We used Autodesk GBS web-based tool which runs DOE-2 at the background. Autodesk Revit and GBS are interoperable with each other, we exported BIM of homes as a gbXML file. GBXL is editable spread sheet with DOE-2 inputs. It embeds all the parameters assigned in Revit environment. After adjusting the parameters for multiple energy analyses run, we uploaded them to GBS and performed energy simulation.

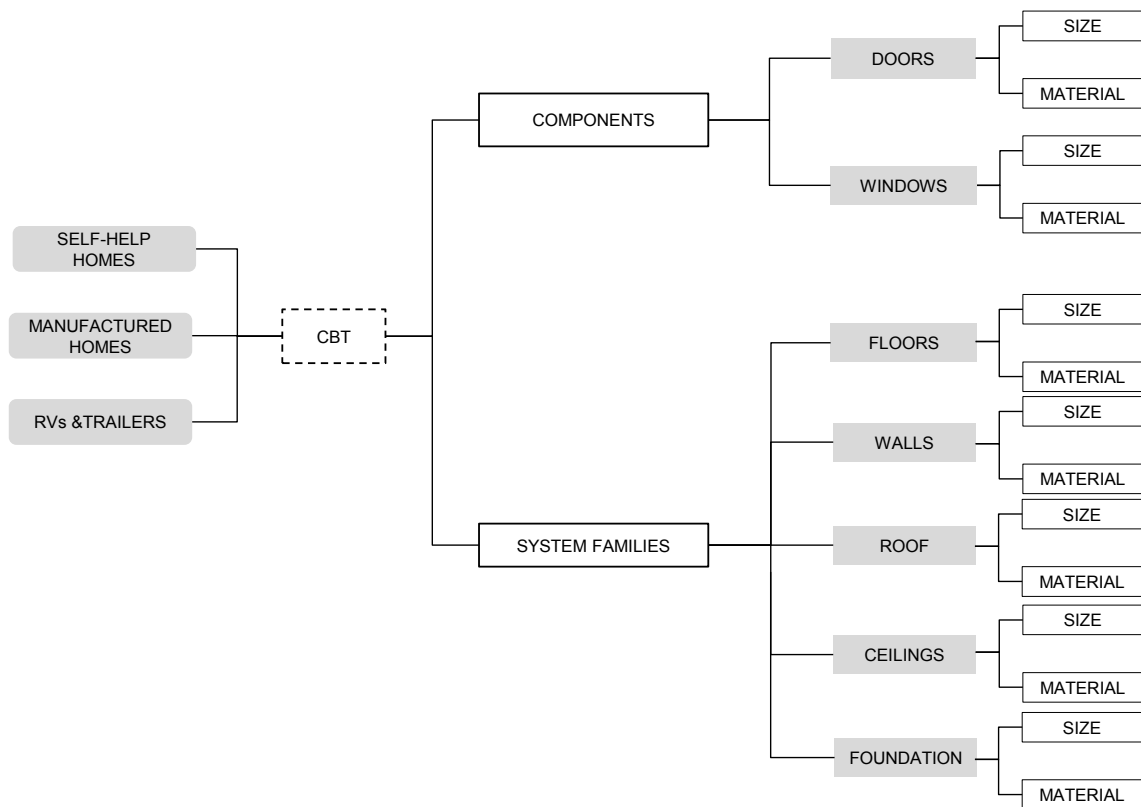


Figure 1: Conceptual Diagram of CBT Development

Although Autodesk Revit has its own library of materials and building component and system families, they are inadequate to model the non-standard constructions in colonias homes. We developed CBT as an Autodesk Revit template file which includes unique library of building components and materials used in colonias homes. The Colonias Autodesk Revit Library encompasses existing architecture and construction patterns of colonias self-help housing in and near Laredo, Texas. Three types of homes observed in Colonias were considered for each component and system family (Figure 1). The variation between each type was determined by considering size and material parameters. Age is also another important parameter in terms of the likely construction methods within a home (Ward et al. 2010). We have referred to age parameter to identify scenarios for unknown parameters.

3.1 Development of CBT

Three colonias in Laredo, Texas were selected as a test case. Data was collected from 30 self-help houses as a representative sample from these colonias using face-to-face interviews with residents and on-site home inspection. We used two data collection instruments: (1) interview questionnaire for residents on construction techniques of their houses and (2) home inspection checklist for site observation (Yenerim, 2014). The data collection instruments were built on existing studies (Keall et al. 2010; Meng and Hall 2006; Reimers-Arias 2009; Ward et al. 2010).

We were able to compile a list of materials used and measure the home. Three types of houses, self-help homes, manufactured homes and recreational vehicles or trailers, were considered, and represented within under categories. To that extent, CBT design kit includes a wide range of materials and construction techniques. However, there are several unknown data elements that are required for energy simulation: (1) R-values of the building components, (2) heating and cooling systems, and (3) air infiltration value. To overcome this challenge, we performed multiple analyses to produce a probabilistic estimate for energy consumption.

3.2 CBT Test Case

The use of the CBT is demonstrated through one self-help colonias home. The home was built in three stages in 1999, 2001 and 2002 (Figure 2). It comprises wood frame structures on concrete slabs with shingles on the roof. Residents reported to have used tile as a floor finish. According to the interview with the residents, first, they have built a structure with 1 kitchen, 1 dining room, 4 bedrooms, and 2 bathrooms. The second stage structure consists of 2 bedrooms and 1 bathroom. In the final stage, the residents added 1 bath and a porch.

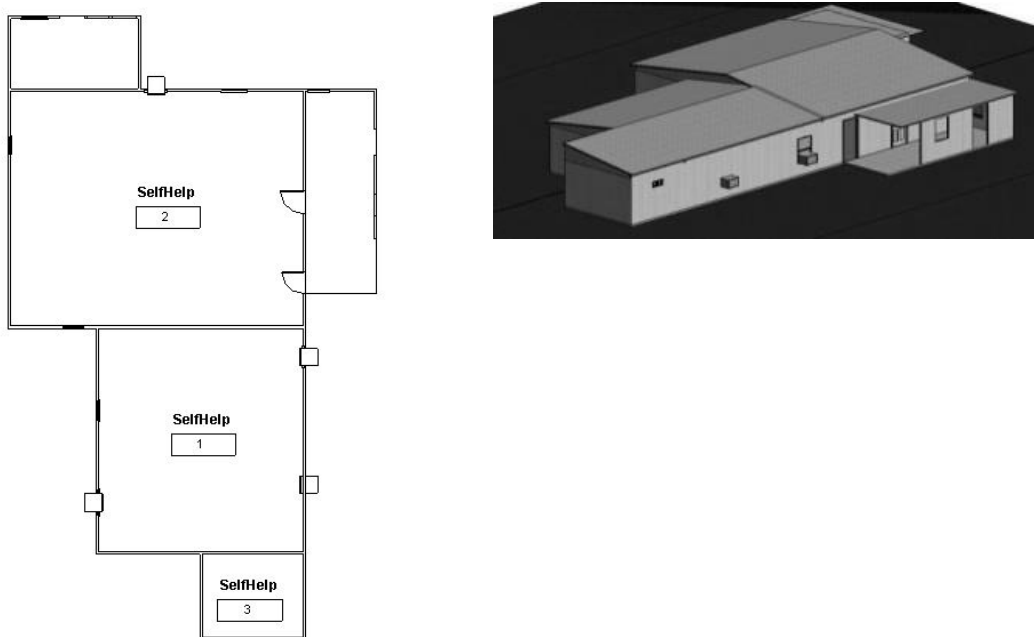


Figure 2: Plan of the home (left) and BIM of the home created by utilizing CBT (Yenerim 2014)

To model the house without R-values, HVAC type, and air infiltration value, we developed 20 scenarios and ran 20 simulations to generate a probabilistic range. We have tested a combination of two educated guess on air infiltration values by utilizing Lawrence Berkeley National Laboratory database (Bazjanac 2008), two different insulation thicknesses on building components, and natural ventilation, and 3 HVAC systems (Yenerim 2014). The results suggest that total annual electricity use ranges from 15,806 kWh to 25,141 kWh and total energy use intensity falls between 37 and 60 (kBtu/ft²/year).

Table 1: 20 energy simulation runs

		RUNS	Annual Elec Use	Annual Fuel Use	EUI
SCENARIO-C	WORST INFILTRATION	WORST.xml	17,373	7	40
		WORST.xml_Infiltration_0.17_ACH	15,806	7	37
		WORST.xml_Infiltration_3.5_ACH	20,829	7	47
		HVAC_RES 17 SEER/0.85 AFUE Split/Pkgd	17,171	13	43
		HVAC_RES 14 SEER/0.9 AFUE Split/Packaged Gas	24,829	13	59
		HVAC_RES 14 SEER/8.3 HSPF Split Packaged Heat Pump	24,717	7	56
	MOST LIKELY INFILTRATION	MOSTLIKELY.xml	15,990	7	37
		HVAC_RES 17 SEER/0.85 AFUE Split/Pkgd	16,224	10	39
		HVAC_RES 14 SEER/0.9 AFUE Split/Packaged Gas	24,038	10	56
		HVAC_RES 14 SEER/8.3 HSPF Split Packaged Heat Pump	23,661	7	53
SCENARIO-B	WORST INFILTRATION	WORST.xml	17,790	7	41
		WORST.xml_Infiltration_0.17_ACH	16,174	7	37
		WORST.xml_Infiltration_3.5_ACH	21,302	7	48
		HVAC_RES 17 SEER/0.85 AFUE Split/Pkgd	17,443	15	45
		HVAC_RES 14 SEER/0.9 AFUE Split/Packaged Gas	25,090	15	60
		HVAC_RES 14 SEER/8.3 HSPF Split Packaged Heat Pump	25,141	8	56
	MOST LIKELY INFILTRATION	MOSTLIKELY.xml	16,361	7	38
		HVAC_RES 17 SEER/0.85 AFUE Split/Pkgd	16,467	12	41
		HVAC_RES 14 SEER/0.9 AFUE Split/Packaged Gas	24,293	12	57
		HVAC_RES 14 SEER/8.3 HSPF Split Packaged Heat Pump	24,054	8	54
		MAX VALUE	25,141	15	60
		MIN VALUE	15,806	7	37
		MEDIAN	19,310	8	46

Modeling and analysis required less than a day. Therefore, it is very practical.

4. Discussion

Our investigation shows that, using CBT, a researcher can model homes and communities in a very quick way and can perform energy simulation to predict their current energy use. Having an estimated current energy use of individual homes can lead to an estimated energy use of the community. These numbers can be useful for policy implications and to monitor the growth and its reflection in energy consumption. These data can be assembled as a database for colonias and be updated as new data collected and as homes are updated. Scenarios of future homes and communities can be modelled with relative ease, allowing policy-makers to consider different outcomes and ranges of outcomes. This process of developing and utilizing BIM toolkit for modeling informal settlements and perform energy analyses can be applicable to other informal settlements as well.

Having visual models of homes would be beneficial for policy makers as well. They can have knowledge about existing architectural practices. By architectural practices, we refer to both design patterns, and construction standards and materials. It is crucial because they reflect the traditional and cultural mind-set of residents. It is very important for policy makers to

understand the existing construction activities adopted by residents in order to propose improvement techniques and methods acceptable by residents.

By utilizing aerial photography from different years, an analyst may examine the changes on individual homes and on a community as a whole. It may be possible to calibrate a model of a community based on change of building form and energy use over time, enabling increased accuracy of predictions for the future.

In order to make the results more accurate and reliable, more accurate and detailed data collection for each home is required. By increasing the number of sample homes, and also number of runs, energy simulation results become more accurate. We have tested only 20 scenarios on a single home for this study and have a range of energy use of the residents. However, with more and more energy simulation runs of a significant number of homes in a community, it would be easy to extrapolate these results to the whole community and have a lower standard error of the whole community.

5. Conclusions

Although BIM has been widely used as a design and modelling tool for formal structures, applications in informal settlements context is new. Nevertheless, BIM is a powerful tool for modelling informal settlements. Using a toolkit, such as the CBT, it is possible to model rapidly a home or many homes in an informal settlement. Missing data, such as insulation and infiltration levels, may be estimated by systematically varying parameter values and conducting energy simulations to reach a probable energy performance. Given the BIM of the home, it is possible to project future modifications to the home and estimate future energy costs, aiding policy-makers to project future energy needs and guide development of policy. As the sample of homes in a community is increased, the range of probable community-wide energy consumption should narrow, leading to greater confidence in predictions.

We demonstrated how BIM of informal homes and simulation can be used to inform, and determine policy decisions related to design and construction of homes. In this paper, we argued that multiple analyses can produce a probabilistic estimate of energy consumption. As the sample of homes increases, the accuracy of the energy consumption of the community increases, aiding support of policy decisions. For example, the uncertainty around the energy analysis of a single home can be demonstrated by the standard deviation of possible outcomes of its simulation. This uncertainty can be quite large for a single home since the unknowns associated with the home can create a big range of energy analysis outcomes. As we repeat the analysis with different houses and increase our sample size, the standard error (variation of sample mean) would decrease and the precision of the analysis around the average single home would increase. The larger the sample, the more precise our analysis would be for the total community.

Having the CBT and BIM of homes allows testing and evaluating alternative materials, insulation, heating and cooling systems and even alternative layout design options (Yenerim

2014). Besides estimating energy use based on heating and cooling loads, BIM of homes has other benefits; it allows users to perform wind, daylighting, and cost of the home.

To sum up, by having 3-dimensional BIM of homes and parametric simulation results, policy makers could determine not only required insulation improvements, glazing options, or HVAC system alternatives for the existing structures to upgrading existing informal settlements, but also the form and location of the additions. Moreover, policy makers could provide low-cost passive design techniques such as extending roof overhangs, use of porch or planting trees for shading purposes. Our focus is Texas colonias in this study but the 3-dimensional BIM of homes and energy simulations of colonias homes in other states such as New Mexico, California and Arizona could also enable policy makers to identify scenarios considering energy use in different climates. To that extent, developing a toolkit for different colonias and creating BIM of homes located in different states would be beneficial for policymakers. As these are self-built and self-managed homes, residents can improve their homes to meet the required building codes for this area by themselves.

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An Investigation of BIM Readiness of Owners and Facility Managers in Singapore: Institutional Case study

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Abstract

Over the past five years from 2010 to 2015, Building Information Modeling (BIM) has gained significant popularity in Singapore's building and construction industry with the implementation of the first BIM roadmap by BCA (Building Construction Authority). It is observed that, the project stakeholders adopt BIM in their work flow mainly in the design and construction processes. It is unclear the extent to which successful BIM adoption be extended to post-construction Facility Management (FM) stage. Considering that most of the buildings in Singapore are existing buildings constructed and operated without any BIM experience, it is important to know how the building owners react to BIM adoption in FM. In this research, we selected a large institutional organization in Singapore to investigate the BIM readiness of the building owner and facility managers. Our aim is to evaluate the awareness and willingness of BIM adoption, identify the motivators and challenges of BIM implementation, and explore the strategies and potential issues of BIM adoption in FM. The research provides value to the implementation of the upcoming BCA's second BIM Roadmap with the focus on process transformation, BIM for specialty contractors, BIM for design-for-manufacturing-and-assembly, BIM for facilities management, and BIM research and development. We adopted a qualitative method of unstructured interview with open-ended questions to collect rich information and data from the interviewees with greater details and depth of content. The transcripts were coded for qualitative analysis. Interview data revealed that the owner and facility managers have a fairly high degree of awareness of and willingness to BIM adoption in FM, with many external and internal motivators and challenges identified. Some potential issues which may hinder the BIM adoption are discussed in five key components, i.e. people, process, technology, policy, and BIM manager.

Keywords: Building Information Modeling, BIM, Facilities Management, FM, Institutional Buildings, Singapore.

1. Introduction

Building Information Modeling (BIM) is an emerging virtual design and construction technology which has been revolutionizing the architecture, engineering and construction (AEC) industry over the past decade. BIM redefines the process of asset delivery and provides multi-disciplinary virtual models generated from a wide range of data and exchange files in many levels of detail or development (i.e. LOD, a measure of project development and information certainty in the associated BIM models; see also BIM forum, 2013) throughout the life cycle of building and infrastructure development and operation. The three-dimensional (3D) models and the rich underlying data allow for various trades to collaborate and coordinate the information with each other to improve productivity and increase return on investment (ROI) attributed to the virtual modeling and proactive problem solving approaches.

Researches on BIM have increased significantly in the recent years. Yalcinkaya and Singh (2015) reviewed 975 academic papers related to BIM between 2004 and 2014 and reported that out of 220 papers in the factor of “BIM implementation and adoption”, 4% were published between 2006 and 2008, 38% were published between 2009 and 2011, and 58% were published between 2012 and 2014. Other BIM research factors include energy management, academy and industry training, information exchange and interoperability, safety management, urban/building space design and analysis, construction and project management, design codes and code compliance, as-is, as-built data, promotion and technology development, maintaining and managing facilities, and architectural design process. The following trends can be observed: a) BIM researches become more and more popular since 2004, especially after 2009; b) BIM researches cover a broad range of topics in the building life cycle; c) the majority of BIM researches focus on the project development phase, while researches in the post-construction phase are limited; and d) BIM researches on owners and facility managers are much less than those on architects, engineers, and contractors among all the project stakeholders.

At present, the benefits of implementing BIM in the design and construction phases have been increasingly recognized and realized (Barlish and Sullivan, 2012; Bryde et al., 2013; Eadie et al., 2013). However, the benefits of implementing BIM in the whole of building life cycle, especially in the operation and maintenance phase, have not been equally demonstrated and explored. For most asset owners, the true benefits of BIM in the post-construction stage are difficult to be measured using quantitative means. Therefore, evaluation should not only focus on the operational improvements enabled by BIM, but those of a managerial, organizational, infrastructure and strategic nature (Love, et al., 2013). Adopting BIM in the traditional facility management (FM) workflow requires a fundamental change of business practices, rather than merely a technical enhancement. The barriers need to be identified and evaluated at various levels of business organization, within which the majority of workforce currently have little or no prior experience in BIM applications.

This research project aims at identifying the barriers and drivers of large clients towards BIM adoption and implementation in the post-construction phase. It focuses on the perspectives of building owners and facility managers, who are the decision makers in adopting BIM and the executing BIM implementation, respectively. This project is part of a comparative research of BIM adoption between Australia and Singapore for whole of life BIM model delivery (from project inception stage to facility management stage). We conducted five formal interviews with five employees of a large institutional organization in Singapore, who represent the owner, the FM team, and the project management (PM) team. The audio recordings were transcribed and coded for qualitative analysis. The results generated from this study help understanding the challenges and motivators of BIM adoption in FM, assess BIM readiness of owners and facility managers in the context of Singapore institutional built environment, and provide strategic recommendations in several political, technological, economic and social themes.

2. Background

Singapore has substantially accelerated BIM adoption with the implementation of the first BIM roadmap by BCA (Building Construction Authority). Over the past five years from 2010 to 2015, BIM has gained significant popularity in Singapore’s built environment. Figure 1 shows a summary of the challenges and strategies in BIM adoption identified by BCA (Cheng 2011). BIM implementation in the public sector was initiated with selected projects between 2010 and 2012 (see Table 1). Subsequently, mandatory BIM e-submissions were enforced progressively between 2013 and 2015 with specific milestones given to the architecture and engineering disciplines. By July 2015, it was stipulated that architecture and engineering BIM e-Submission be implemented to all new building projects with gross floor area (GFA) of 5,000 m² and above.

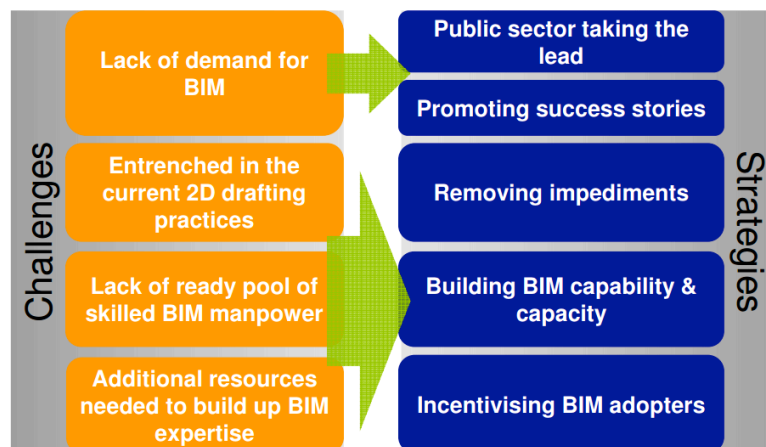


Figure 1: Singapore BCA’s first BIM roadmap: Challenges and Strategies

Table 1: Singapore BCA's first BIM roadmap: Implementations

Year	Implementation
BIM Implementation in the public sector projects (2010-2012)	
2010	Establish Centre for Construction IT help key agencies and construction firms to kick start BIM
2011	Work with key agencies on pilot projects
2012	Work with key agencies to prepare consultants and contractors who undertake the public sector projects to be BIM ready
Mandatory BIM e-Submission (2013 – 2015)	
2013	Mandatory Architecture BIM e-Submission for all new building projects > 20,000 m ²
2014	Mandatory Engineering BIM e-Submission for all new building projects > 20,000 m ²
2015	Mandatory Architecture & Engineering BIM e-Submission for all new building projects > 5,000 m ²

BCA's first BIM roadmap primarily targeted on architects, (structural, mechanical, electrical, and plumbing) engineers, and contractors. From a discussion with several BCA staff in the late 2015, it shows that the majority of submitted BIM models are created at LOD 150 to 200 levels (i.e. the schematic design stage) just to meet the compliance requirements. Nevertheless, it is no doubt that the mandatory BIM submissions have greatly accelerated BIM adoption in Singapore in the design and construction workflow, though there is still a long way to go for BIM adoption and implementation to be extended to the entire building life cycle.

In October 2015, BCA announced the second BIM roadmap (2015-2020) which promotes BIM adoption to all asset stakeholders in the whole building life cycle. Six key measures were introduced, including: a) driving BIM collaboration throughout value chain; b) building BIM capability of specialist contractors; c) providing new training programs at all levels; d) promoting BIM for Design for Manufacturing and Assembly (DfMA); e) promoting BIM for FM and smart building; and f) promoting BIM-based research and development (R&D).

To extend BIM adoption into the post-construction phase, a paradigm shift of the present best practices in building life cycle management is required. Admittedly BIM for FM applications are still rare in Singapore according to the discussion with the above mentioned BCA staff. This is not only because of the fact that the vast majority of buildings do not have any BIM models or do not have BIM models with sufficient details, e.g. LOD 500 as-built models or LOD 600 as-is models, but it imposes great challenges to five key components in the built environment, i.e. People, Process, Technology, Policy, and BIM manager (Bew and Underwood, 2010; BIM Journal, 2011). While 'People' and 'Process' are instrumental to improvement and change, without 'Technology' these elements cannot be sustained. BIM adoption will inevitably result in major transition of skills, practices, and knowledge associated with people and processes by taking advantage of technology advancement and subsequently enabling more technological innovations. 'Policy' plays an important role in terms of providing standards and guidelines to mitigate the risk of mistakes and failures. 'BIM manager' is a critical success factor to ensure the other four components work in unison.

Considering that most building owners and facility managers in Singapore have little or no real experience in BIM, which is evident from the lack of BIM adoption and implementation in FM, it is valuable to investigate the BIM readiness of building owners and facility managers in terms of awareness, willingness, motivators, challenges, strategies, and roadmap. Some benefits of the research are as follows. First, it helps understanding the current status of BIM adoption in the FM stage before the second BCA BIM roadmap is implemented. Second, it helps identifying the key drivers and barriers of BIM adoption and implementation in FM. Third, it helps establishing

an enhancement framework to expedite BIM for FM. Last but not least, it allows to benchmarking the performance of BIM for FM in Singapore with those of other countries for further improvement.

3. Research Settings

The main objective of this study is to identify the barriers and drivers for BIM adoption in FM and evaluate the BIM readiness of owners and facility managers in Singapore. We decide that a qualitative method of unstructured interview with open-ended questions is more suitable for collecting rich information and data from the interviewees with greater detail and depth in content. A large institutional organization in Singapore is selected as the case study, which owns more than 200 buildings and has hundreds of internal staff and external workers. The organization still adopts a 'traditional' facility management framework, where the workflows are based on 2D drawings. Most of the existing buildings do not have BIM models. Several new buildings are being tendered or constructed with BIM models at LOD 200 to 300 levels (i.e. the detailed design stage). This is a typical large organization in Singapore, in terms of FM practice. It has not formally started BIM implementation in the FM, but some BIM applications have been initiated in the PM phase.

The interview team comprises three co-authors of this paper, who have fairly good understanding of BIM in terms of theory, technology, best practice, and the BCA's BIM roadmaps. Two interviewers are based in Singapore and familiar with the local industry context. The other interviewer is based in Australia, who provides an additional perspective to this research.

The interviewee team comprises five employees from the same organization. Three interviewees are from the department of facility management: one director (F1), one senior associate director (F2), and one contract manager (F3). None of them have real BIM hands-on experience. The other two interviewees are from the department of project management under strategic planning division: one senior associate director (P1) and one assistant manager (P2). P1 has no prior BIM hands-on experience. P2 previously worked as a BIM coordinator in a design firm for two years. The interviewee team consists of senior management, middle management, and executives of both FM and PM processes. Collectively, they represent the building owner and facility managers to provide a reasonable sample for the research study.

Questions cover the interviewee's background and awareness of BIM related to his/her work, the interviewee's willingness of BIM adoption in his/her workflow, the challenges or barriers of BIM adoption in FM, the motivators or drivers of BIM adoption in FM, and the strategies to be taken.

Figure 2 shows the research framework where the key value of this research is to provide strategic recommendations to: a) remove the barriers of BIM adoption in FM at organizational level; b) increase the motivators of BIM adoption; and c) facilitate the implementation of BCA's second BIM roadmap.

One of the limitations admitted by the authors is that this research is based on a single case study. The validity of the research findings are subject to further validations with other organizations in Singapore, though many of them may share similar sentiments due to the rather standardized industry environment and the strong policy and regulatory guidance. Meanwhile, the open-ended questions allow the interviewees to share insightful experiences and opinions based on their job backgrounds. However, it is difficult for the authors to provide a list of

individual questions here as most questions (except for the opening ones) are based on the conversation context. Nevertheless, the questions are primarily focused on the awareness, willingness, challenges, motivators, and strategies of the BIM adoption in FM. Lastly, the authors adopt a simplified framework in this paper based on Figure 2, without extensively exploring the interrelationships of various interviewee inputs, which will be covered in another paper.

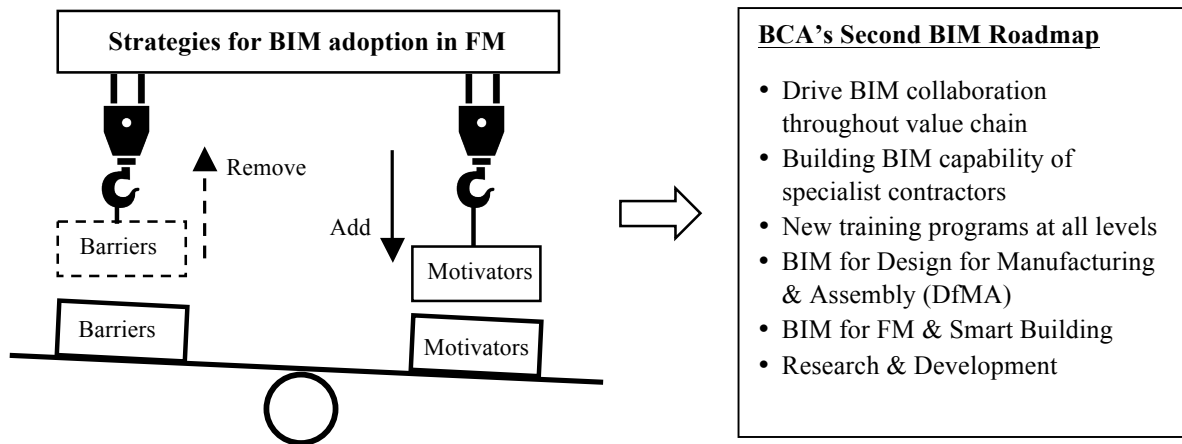


Figure 2: Research framework for promoting BIM adoption in FM

4. Data Collection and Analysis

All interviews were audio recorded and transcribed. The transcripts were then coded in NVivo for qualitative analysis. The top level coding structure includes the following elements: status, motivators (or drivers), challenges (or barriers), and strategies.

4.1 Status of BIM adoption in FM

The interviews with F1, F2 and F3 indicate that BIM for FM has not been adopted in the organization. All five interviewees are aware of BIM, though only interviewee P2 has prior BIM hands-on experience in another design firm. Regarding the willingness to adopt BIM for FM, interviewee F1 (FM director) expressed that “*We are keen to start it*”, “*We don't let the authority or the agencies push us to do that. We feel if it is the right way, let's do it*”, “*In fact, we are quite tempted to do that, just by lock, stock and barrel*”, and “*So now the question is how to create that kind of journey ourselves*”. It is therefore clear that the organization is at the early stage of BIM adoption, and the senior management of FM has a strong interest in initiating BIM adoption and implementation.

4.2 Motivators of BIM adoption

Motivators are a combination of factors that encourage or force BIM adoption in the organization. Interviewee F1 admitted that “*there is this external push and this internal push*”. We classified these factors as external motivators and internal motivators.

External Motivators

The first external motivator is **authority encouragement and enforcement**. In Singapore's context, currently there is no policy requiring or insisting that FM group takes up BIM, but BCA encourages early BIM adoption for FM. F1 disclosed that funding could be available if they start looking into it. Similar case can be found in the implementation of BCA's first BIM roadmap, where BIM adoption was first tested out in the public sector between 2010 and 2012, and subsequently mandatory adoption was required for the industry once the experience was built up. Likewise, it is possible in the future that using BIM for FM becomes a compulsory requirement, which will increase the risk of non-performance.

The second external motivator is **peer effect**. F1 disclosed that he was invited to participate an overseas study trip to Europe, and witnessed some best practices of BIM applications for FM. F1 commented that the BIM-FM system demonstrated is at "*mature stage. They are using at the facilities management stage. ... Here they call it various D: 3D, 4D, 5D and 6D. They are at the 6D level right now*", and "*We didn't see the difficulty, how they reached it. We saw the outcome, the final outcome that it really benefits the facility management group, yeah, and their operators. In fact, their contractors are all into that system as well; it's all interrelated*". Peer effect or peer pressure is a well-known influence that encourages people in a peer group to change their attitudes, values and behaviors to conform to those of the influencing group or individual. In this case the showcase of mature BIM applications for FM certainly provided a high level inspiration, especially when the influenced peer already had a strong desire to adopt BIM.

The third external motivator is **organizational image**. F1 disclosed that "*being a leader in many areas, at the senior management level when I attended the meeting they also say - why don't we just take a step forward?*".

Internal Motivators

The first internal motivator is **benefits to organization**. F1 disclosed that "*We can see the benefits at the facility management level rather than at construction level*", and "*looking at from other requirements like Green Mark or even like Barrier-Free Accessibility, we believe in it; actually it works*".

The second internal motivator is **desire to be ahead**. F1 disclosed that the senior management of the organization suggest "*So instead of being pushed, why don't we just take the first step and get it done ourselves?*".

The third internal motivator is **catching up with the PM office**. F1 disclosed that the FM department in the organization is linked to the PM department. Based on the BCA's first BIM roadmap, most new buildings of the organization will have BIM models submitted in the future. "*So I am doing the catching up with the other group*".

The fourth internal motivator is **benefits to FM**. F1 suggested two benefits as data and data analytics, which could enable preventive and predictive FM. "*I would say data; I think more importantly, I think it is the analytical part of it. I think, okay, if I don't look at that difficulty, I look at the benefit straight away, I think they link all the data together and generate a lot of what we call analytics to guide the facility management in terms of preventive maintainers. So we don't have to do what we call... 'guessing game'.*" "*So we should move more to preventive, even better predictive, and I think we have this kind of expectations from various laboratory and institute that we should actually be, keep improving on maintenance stuff, before it breaks down.*

So I think it ties with a core mission, yeah, and these tools really, from what they demonstrated is definitely really useful.” F2 (zone manager) suggested an example of asset lifecycle planning. *“Asset lifecycle replacement for example. So right now we are not able to fine tune the real details and currently we don’t have the nitty gritty details of specs ... if everything could be easily integrated into one source where everything is overlapped, so it’s not only just BIM only but that’s why we are moving towards into our first phase which is going into the modular software where we can actually track repair cycles.”*

The fifth internal motivator is **benefits of efficiency and cost**. F2 believes BIM could help speed up information retrieving and handling. *“I think it’s more about being able to manage information a lot faster. Instead of having to work on just CAD drawings and then having to put information together for different sources you have everything as one integrated source. That will cut time pretty much.”* F3 (contract manager) commented several times about the potential reduction of time (and cost) in retrieving drawings and other related data. *“Yes they will need probably I would say at least 20-30% of their time (to retrieving information).”*

Other mentioned benefits include visualization, clash detection, scheduling, and construction management, which are related to the native benefits of BIM technology.

4.3 Challenges of BIM adoption

The interviewees disclosed many challenges concerning BIM adoption and implementation, which are summarized as follows.

- **Cost.** F1 disclosed that *“normally cost and resources are the barriers”*, and there is a lot of initial investment as well as maintenance cost to create and operate the infrastructure for BIM-FM. Estimated cost for the organization over a period of 10 years could exceed 10 million Singapore dollars.
- **Time.** F1 disclosed that it took 12 year for the European organization he visited to reach mature stage of BIM-FM application. Although he is confident in shortening the duration to less than 10 years, it would still be a long period of time and therefore there could be many uncertainties. *“Normally, once I start showing ten year, or data that shows what goes beyond 10 years I know I will lose their interest.”*
- **Return of investment (ROI).** F1 disclosed that the initial calculation of ROI (for the planning purpose) is rather low, around 6% to 8%, which makes it difficult to get support from the senior management. *“Unlike my other projects where I show returns of 12 to 15%, and let’s say solar PV, renewable energy; it scored a higher return, 12%. And even then they’re still hesitant, because 12%, because there will be a lot of unseen things.”*
- **Technical competency.** The organization has over 100 internal employees and 2000 external contracted workers for various types of asset operation and maintenance tasks. Most of them do not have much information technology (IT) background. *“So there’s a big gap there.”* Internally, it is estimated that the training cost for BIM is high, and many employees will retire in 10 years. *“So the question is, is it worth it? And second, this group of staff that we have actually at a certain level at age, yeah, they have about maybe 10 more years to retirement.”* Externally, *“getting educate the contractor is another issue because so far even through a normal submission where we got a simple submission for procurement you already have problem. So to get them to use BIM I think it’s a challenge”*.

- **Training and contractor buy-in.** On top of technical competency, one practical challenge is to provide training to the entire ecosystem to ensure sufficient qualification. This is not a trivia task considering the large number of internal staff and external contractors.
- **BIM model availability.** The organization has more than 200 buildings. *“The drawings are not being related to BIM format. For us to convert to that level is a massive exercise, so I think that that’s one hesitation.”* In fact, this is a major barrier for any organization to begin with BIM adoption.
- **Software.** At present, a mixture of vendor supplied and in-house developed proprietary software are seen in the BIM-FM applications. Interoperability is a common issue. The interviewees expressed their concerns about software selection and maintenance.
- **Organizational structure change.** The organization is currently undertaking several structural changes in the area of asset management. Drawing and documentation management is one of the examples, which resulted in temporary impact to the business operation. If BIM adoption is determined, additional complexity would be created.
- **Investment priority.** FM investment has lower priority, compared with other core business functions, in the organizational budget planning.
- **Tangible results.** Intangible benefits need to be translated into dollars or tangible value for quantitative evaluation and comparison, otherwise it is hard to convince the senior management. Meanwhile, clear objectives, path, and schedule need to be provided in the proposal.

4.4 Strategies for BIM adoption

Although the organization has not formally started BIM implementation for FM, the experience shared by the interviewees is still useful to the non-BIM users as a reference. The strategies summarized from the interviews include the following.

- **BIM study trip.** It seems that peer effect has a very strong influence in encouraging BIM adoption. It is not a simple duplication. The interviewee who joined the study trip did make a lot of contemplation and attempted to adapt the practice into the local context. The biggest value is that the visitor could see the final outcome and the tangible benefits of BIM-FM applications. Another value is to allow the visitor to make more realistic estimation of time, cost, schedule, and resources.
- **Case study.** BIM implementation is no-double a long and tough journey. It is less risky to start with simple case study, for example one or two new buildings. The downside is that it will require a long time to generate sufficient feedback.
- **Jump start.** Time is critical. Another strategy is to take the action immediately, on certain areas first. *“... they’re asking us to jump start, certain areas don’t bother, don’t go and do, don’t try, no more experiment. Just jump start.”*
- **BIM department.** F1 disclosed that *“I definitely need a BIM department to push item because every initiative, whether it’s on safety or on BIM, definitely you always need a champion there, and this is why I’ve got my colleague.”* Before the BIM department is established, he suggested appointing a few people to be the champion. *“I was following the other safety model where a few people are singled out to be the champion for the BIM, and then for example, it leads to changes into the organizational group. So I am envisioning the same thing for my colleagues, those from contract and procurement.”*

- **Progressive cascading effect.** The interviewee suggested a progressive cascading effect to build the system and let the contractors to follow up, by the influence of both owner and authority. *“I do not see immediate, a big jump immediately. I see a gradual transformation. I definitely need to build up the BIM champion. I need to put that into every part, procurement part, it’s what the contractor part, to ask them to be slowly moving to the BIM, enable part of it. And it cascaded down to all my partners and the suppliers, and of course I hope that the agency can support me on this item because it takes two roles. Mine will be the encouragement part because I cannot force it very hard because it will result in a high construction or management cost. But hopefully they just see a push from their levels, and to make sure every time the contractor try to get certification, this definitely will be requirement.”*
- **BIM model and data acquisition.** BIM model and accurate data are two major constraints and should be handled with high priority. *“Now, we were hoping at new buildings level the consultant, contractors, even at the building owner level, we’ve got all the inputs correctly, so when the drawing reach us we don’t have to do so much work, and then we can straight, start extracting the info or make the use of all this data that’s residing in the BIM.”*
- **BIM Specifications in the contract.** Previously BIM requirements were not explicitly indicated in the contract. P1 (strategic planning manager) disclosed that *“now we are starting to put in specifications for our BIM projects, ... we are in the midst of appointing a consultancy for first project where we will have a full suite of BIM implementation, so that’s where we are as today”*.
- **Standard information template.** The interviewee F2 talked about standard information template for contractors. This practice has been seen in the pilot COBIE applications, i.e. Construction Operations Building Information Exchange (Smith E et al. 2012).

5. Discussions

The interviews show that the organization under investigation has fairly high BIM readiness by owner and facility managers in terms of awareness and willingness. However, many related issues cannot be ignored, which are discussed with the previously mentioned five key components: people, process, technology, policy, and BIM manager.

- **People.** Firstly, the interviewees P1 and P2, both from the project management office, expressed their concerns on the shortage of skilled manpower. *“whether it is basic draftsmen, or BIM coordinators and BIM managers, especially for local employees, it is hard to find, and if they are to look for foreign employees, they are also constrained, make sure manpower are on station, all this, so it’s a challenge, so everybody is hungry for the manpower, everybody is finding, so, this is the main constraint here”*, and *“So I guess our main challenge is basically resources, like people with the right knowledge and to drive it in that direction”*. The same issue of skilled manpower will be seen in the FM-BIM process. Secondly, for the hundreds of existing manpower internally and externally, most of them are non-IT trained. It takes many measures to upgrade their skills and readjust their scope of work to adapt to the new workflow. Thirdly, future FM-BIM applications will require new talents in many new areas (such as high performance building science, sensors, data processing and analytics, and smart applications), who may be in a shortage as well.

- **Process.** The success of BIM for FM is strongly impacted by the upstream PM processes. FM-BIM requires high level of detail, ideally at LOD 500. However, most present building projects in Singapore rarely deliver BIM models beyond LOD 350 or 400 (i.e. the construction stage). Many facility managers may not have chance to obtain complete BIM models. On the other hand, advanced FM-BIM applications (such as preventive and predictive analyses) require deep knowledge in the domain. With the complexity of FM BIM models, a lot of research and development as well as process integration are needed.
- **Technology.** The BIM technologies can be broadly divided into two categories, geometric and non-geometric. After over a decade of development, software solutions have become more and more mature in geometric modeling, object library creation, and interoperable integration. Nevertheless, modeling and model updating are still largely based on the manual processes, which are time consuming and costly (Volk et al. 2014). This is one of the major challenges of BIM adoption in the FM. The non-geometric technologies include a wide spectrum of information and communication technologies (ICT) and data technologies. FM-BIM is still one of the areas that need significantly more innovations, for example, smart and sustainable applications.
- **Policy.** The present BCA's second BIM roadmap provides indicative guidelines. For the FM industry to massively convert to the BIM platform, a lot more supports and incentives are needed. Examples are pioneering local FM-BIM showcases, providing FM-BIM guides, providing FM-BIM benchmarks and appraisals, providing FM-BIM training and certification, etc.
- **BIM manager.** An experienced and qualified BIM manager is critical to the success of BIM adoption and implementation in FM. The BIM manager must not treat FM-BIM as little "bim" (lowercase), in terms of software. He or she must treat FM-BIM as BIG "BIM" (uppercase), in terms of integrated design and exchange of project data (Jernigan 2008). BIM is a combination of tools, platforms, processes, databases, communications, and organizational cultures. The BIM manager is the person to maximize the benefits of this new infrastructure to the FM teams.

6. Conclusions

With the release of Singapore BCA's second BIM roadmap, applications of BIM for facility management are recommended in the Singapore built environment sector, which potentially become a compulsory requirement in the future. This research project aims at investigating the awareness, willingness, motivators, challenges, and strategies of building owners and facility managers. A qualitative method of unstructured interview with open-ended questions were adopted to collect rich information and data from the interviewees of a large institutional organization in Singapore. Interview data revealed that the owner and facility managers have a fairly high degree of awareness and willingness to adopt BIM in FM. Three external motivators are authority encouragement and enforcement, peer effect, and organizational image; and five internal motivators are benefits to organization, desire to be ahead, catching up with the PM office, benefits to FM, and benefits of efficiency and cost. The challenges can be found in many aspects, which include but are not limited to, cost, time, return of investment (ROI), technical competency, training and contractor buy-in, BIM model availability, software, organizational structure change, investment priority, and tangible results. Finally, the potential issues related to BIM adoption in FM were discussed based on five components, i.e. people, process, technology, policy, and BIM manager.

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Evaluating the Usability Aspects of Construction Operation Building Information Exchange (COBie) Standard

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Abstract

Constructions Operations Building information exchange (COBie) is a rapidly evolving standard to capture the digital information of facilities. As the building information modeling (BIM) for facilities management (FM) research is gaining greater emphasis, COBie standard is becoming increasingly central to the discussion. COBie can be delivered in different formats. For the ease of use by the end users, spreadsheet format of COBie deliverable is the most applied one since spreadsheets provide some end-user implementation techniques and have been in use for decades. Although the end-users are familiar with spreadsheet actions, dumping all the facility data to a repository with number of workbooks and associated fields has some unintended effects and poses new challenges in handling and using the COBie data. Therefore, this research evaluates the functional and usability aspects of the COBie spreadsheet deliverable from the cognitive perspectives for end-users, and identifies the key points that can increase the functionality of COBie data structure. The research applies the initial phases of design thinking principles to identify the issues with COBie spreadsheet in general by reviewing the literature about spreadsheet design, human-spreadsheet interaction, spreadsheet errors, and information visualization. The identified usability issues and functionalities provide basic steps towards improving the current spreadsheet representation of COBie. The findings will contribute to future development of COBie, driven from the perspective of user interaction and usability.

Keywords: COBie, Facilities Management, BIM, Usability

1. Introduction

In the Architecture-Engineering-Construction (AEC) and Facilities Management (FM) industry, one of the central issues has been to determine how to structure digital information of a facility such that it enables data sharing among different disciplines throughout the project lifecycle. From that viewpoint, there is an increasing call to use Building Information Modeling (BIM) data in FM (Yalcinkaya & Singh 2015), because a lot of BIM data for an upcoming facility is generated in earlier phases of the project, especially in the design phase. Overall, the dependent facility information is created by numerous BIM, FM and construction management (CM) software applications throughout the project lifecycle. However, all these applications structure and present the FM data in their own proprietary formats which causes inefficiencies in interpreting and processing the data. Construction Operations and Building Information Exchange (COBie) is one of the most dominant, open and vendor-neutral industry standard that describes product and process of collecting and validating building lifecycle data generated during various phases of project lifecycle (buildingSMART 2010; East 2007). Although COBie is relatively new when compared with other AEC/FM standards, it is being widely promoted for BIM and FM. The end-result of the COBie specification can be considered as a common template in which the information structure and the delivery format of COBie specification is planned to reduce inefficiencies in facility information handover.

Currently, COBie-based information can be delivered in any of the three formats, IFC STEP (standard for exchange of product model) Physical File Format, ifcXML (extensible mark-up language format of IFC) and/or SpreadsheetML (open XML schema used by spreadsheet application such as MS Excel). IFC STEP and ifcXML can be interpreted and visualized in various parsers and/or web browsers. However, interpreting these formats requires some information technologies (IT) knowledge which not all end-users have. Given the end-users' inexperience and limited familiarity with the first two file formats, spreadsheet has become the most common way to represent COBie. Spreadsheet format of COBie deliverable provides some useful end-user implementation techniques such as sorting, querying, and/or simple mathematical functions if needed. It is human readable, checkable and editable as well. A COBie spreadsheet deliverable includes several workbooks and columns in which the users export the information from BIM and/or computer-aided facilities management (CAFM) software applications' data mapping or export tools; and/or fill in manually. The data is distributed in workbooks and associated columns such that each row includes specific entities of facility data. Depending on the delivery phase and the project size, a COBie spreadsheet can include thousands of rows of facility data.

Despite the easiness of spreadsheets and familiarity of end-users with spreadsheet logic and actions, storing and representing large amount of facility data in a tabular repository with number of dependent sub-sections may have unintended effects and challenges in handling and interpreting COBie data, for example, challenges in visualizing the overall content, duplication of data entries, understanding data dependencies, memory overload due to high amount of number and text-based data, etc. Similar issues are also discussed in the literature about the usability and cognitive aspects of spreadsheet (Chen & Chan 2008; Kohlhase 2013; Hendry &

Green 1994; Thorne & Ball 2008). Accordingly, the main difficulty that end-users have in understanding the data in COBie spreadsheet can be summarized as the high amount of data and lack of explicit dependencies between the cells and workbooks. Users need to recognize the data and their dependencies in COBie spreadsheet, which imposes a heavy memory load. The schema of the COBie spreadsheet is available in COBie Responsibility Matrix (East 2013) to check and interpret. However, handling two separate files or adding one more workbook to the existing COBie spreadsheet may increase the memory load even further. Responsibility Matrix (East 2013) to check and interpret. However, handling two separate files or adding one more workbook to the existing COBie spreadsheet may increase the memory load even further.

In this paper, we highlight and address the complexities and challenges involved while handling and interpreting the COBie spreadsheet. The contribution of this research is twofold. First, we present our findings by reviewing the literature about spreadsheet design, human-spreadsheet interaction, spreadsheet errors, and visualization. We have identified the issues that are common with the COBie spreadsheet representations. Second, we propose a framework to enhance the usability and functionality of COBie spreadsheet representation. Findings of this study and the proposed framework are expected to identify and outline the potential areas of future development for COBie, especially from the point of view usability and interaction with the data.

2. Background

2.1 Development of COBie Standard

In 1983, the National Research Council Building Research Board (BRB) proposed an integrated database solution for facility information (Scarponcini 1996). Other computerized systems such as CAFM, CMMS, etc. were already available to organize, manage and deliver FM information. The variety of software products and their versioning caused inefficiencies in automatic transfer of data. Consequently, the manual information delivery is still commonly used, even though it is inefficient, error-prone and tedious (William East et al. 2012). COBie specification was developed to overcome such challenges and establish a non-proprietary version of exchange data (East 2007). The development process began in 2006 under National Institute of Building Sciences (NIBS) FM and Operations Committee with an extensive review of literature and private industrial/association efforts. The development of COBie standard is mainly focused on two aspects. First, to determine the useful minimum in terms of specific information requirements, responsible actors and associated life cycle phases. Second, to define data exchange standards to eliminate existing inefficiencies in information exchange. The life cycle information exchange were evaluated based on business cases, specific business requirements, information handover plan and implementation with software applications (East 2007). Association efforts played a vital role in the development of COBie. Machinery Information Management Open Systems Alliance (MIMOSA), an industry sponsored non-profit organization, published important specifications such as the Open Systems Architecture for Enterprise Application Integration (OSA-EAI) (MIMOSA 1998) and for Condition-Based Maintenance (OSA-CBM) (MIMOSA 2006). These standards describe how to integrate asset

information and how to transfer information in a condition-based maintenance system. Similarly, IAI and its open-source framework for exchange of facility information IFC, describes the majority of components, systems, ownership and the process history. Twelve published data exchange standards for the process industry were reviewed to identify equipment, process, systems, procurement, operations and management datasets for the development of COBie (East 2007).

The practices of the public sector were also considered in the development of COBie. US Naval Facilities Engineering Command (NAVFAC), Unified Facilities Guide Specifications (UFGS) provides Operations and Maintenance Support Information (OMSI). OMSI as an information package includes the key information produced during design, construction and commissioning of a facility. The information is organized in three groups: facility information, primary systems information, and product data (NAVFAC 2014). The OMSI package is generally submitted in three formats including hard copies, electronic (PDF) format and compatible with CMMS applications. The main information types and delivery phases were evaluated in the development of COBie. The Electronic OMSI (eOMSI) provides the required facility information in a structured spreadsheet file with a specified template, during the information handover. Besides OMSI, the Department of Public Works (DPW) of US offers a specification called Operations and Maintenance Manuals which covers a variety of facility information such as system descriptions, installed equipment lists, etc. This specification was also considered in the development of COBie. Besides these, such specifications and/or submittal processes provided by US Department of Defence and National Aeronautics and Space Administration (NASA) were also considered in the development of COBie (East 2007).

2.2 Human-Spreadsheet Interaction

Spreadsheet platforms are popular tools for storing, analysing and visualizing data across all domains, ranging from business to science. In Human-Computer Interaction (HCI) community, spreadsheet is often referred as a task-oriented platform with high computational power. By providing a combination of an expressive high-level formula language with an easy tabular format to organize and display data, spreadsheets are easy to learn and use. In addition, spreadsheet actions can effectively guide the decision-making process without the need for complex computing actions and professional support. Therefore, the flexible and direct approach to data manipulation and management in spreadsheets has led to a widespread usage (Panko 2000). Besides, almost in every business or professional domain, spreadsheets are not only used as a single-user application, but also in multi-actor environments as a collaboration tool, and as means of communication, exchange and integration of domain knowledge (Nardi & Miller 1990).

Although spreadsheets are powerful, simple, easy-to-use, and facilitate the tasks of single/multiuser organizations, yet crucial errors can easily occur. Several studies mentioned the common mistakes and challenges of spreadsheets usage in different scenarios (Panko 2000; Powell et al. 2008; Chen & Chan 2000). There are two levels of a spreadsheet: (1) concrete and visible surface level, and (2) abstract and hidden level beneath the surface (Saariluoma &

Sajaniemi 1989). The tabular layout appears at the surface level, while the connection of cells is established in a network defined by the dependencies in the deep/hidden level. One of the basic difficulties during the handling of spreadsheets is establishing the connections among the data distributed in cells and workbooks (Hendry & Green 1994). For large spreadsheets like COBie, tabular layouts for textual and numerical data do not show any direct mapping with the deep level; and in most cases, users deduce the semantic connection among the cells, columns and workbooks by visually checking them, which imposes a heavy memory load. Consequently, the process of investigating dependent data can be tedious and error-prone because many spreadsheets, including COBie, contain widely separated data.

Therefore, it is desirable that the data shown at the surface level, and its dependencies with the deep structure, are represented and integrated in a visual and interactive way, such that users can find the relevant information with lesser cognitive load. This remains a challenge in most spreadsheet-based solutions, and this limitation is carried onto COBie by default.

3. Research Method

The primary objective of this paper is to outline the issues which make COBie data less accessible and usable by users, including inexperienced and non-FM and/or operations and management (O&M), who would likely have difficulties in understanding and using the large COBie spreadsheet effectively. To reach this objective, it is essential to understand the characteristics of the existing representation, and the current challenges and expectations of the users, such that these can be addressed through ideations and enhanced features. This research adopts the initial steps of design thinking process which relies on the co-evolution of the problems and solutions through an iterative process (Dorst & Cross 2001; Poon & Maher 1997) to understand the issues with COBie representation, formulate the problem, and ideate the solutions with respect to the findings of the literature review.

The implementation steps of design thinking are generally organized in five basic steps which are: (1) Understand: understanding the experience and expectations of the users, whom we are designing for, through surveys, observation, interaction and/or self-experiencing the problem; (2) Define: processing and synthesizing the findings in order to form a user point of view for the proposed solution; (3) Ideate: exploring the variety of solutions by generating diverse possible solutions from a range of ideas; (4) Prototype: transforming the ideas into a tangible form to experience and interact with the proposed solution(s); (5) Test: testing the prototype, observe desired users' experience and get feedback to refine it. Following subsections present the understand and define sections of the design thinking as applied in this research to evaluate the current spreadsheet representation of COBie standard and understand the issues with it. Since this paper reports a work in progress, the next steps are currently underway and will be reported in future publications.

4. Problem Identification and Definition: Requirement for COBie Improvement

4.1 Step.1 Understand Spreadsheets and COBie Spreadsheet

The first step is to understand the problem context and assess the key challenges in effective usage of COBie spreadsheet in its current form. As described in previous sections, the underlying usability and navigational challenges with large spreadsheet is one of the key challenges and problems that is carried onto COBie by default, and this needs to be addressed. Therefore, it is important to understand how users interact with the large spreadsheets, navigate through the data, and establish the semantic connections; and what are the causes and effects which increase the cognitive load while handling spreadsheets.

Based on literature (Woods 1995; Woods & Watts 1997), it was found that navigation through large spreadsheets affects the decisions and actions that contribute to a user's ability to find and understand the relevant information. When the virtual representation of any type of data is distributed and much bigger than the actual computer screen, users cannot process the data parallel, in-mind, with what they see on screen. Instead, they split up the large structure and navigate the preceding/succeeding sections via zoom and/or move-to actions. In literature, this issue is referred as the key-hole effect (Woods & Watts 1997). Another issue in dealing with large spreadsheets like COBie is getting lost in which the user becomes lost in the virtual environment and fails to achieve the original task while he/she navigates and searches within the data. According to Woods (Woods 1984), the users "... do not know their present location in the system relative to the display structure and find it difficult to decide where to look next within the system" Another problem is referred as trashing (Henderson Jr & Card 1986). As in the COBie spreadsheet, when the user tries to find dependent information -sets- from different workbooks, he/she must serially shift among different workbooks which causes extra time and memory load. The increase in the memory load can also trigger the mental workload by focusing on the interface instead of the original tasks. While the user is experiencing the spreadsheet structure, he/she may need to memorize certain amount of semantic links and paths between different sections to achieve their task. In many cases, the professionals of AEC/FM industry are expected to deliver their tasks in a limited time and under limited sources; and experiencing the COBie spreadsheet within these conditions can be challenging. In this case, users generally tend to adapt their existing work style to the limitations of the environment/systems. To find a specific COBie data, user can simply use the search functionality of spreadsheet applications. However, in case of the need for checking the dependent information of the specific entity, user has to perform this action repetitively.

COBie data can be generated automatically with BIM, construction management (CM), FM software application and/or their add-on modules. This method provides efficiency by enabling faster production and preventing duplications. However, not every software application has the functionality to export all the data required in each workbook of COBie spreadsheet. Besides, COBie is not designed to handle every specific information requirements that can vary in each project. Therefore, users may need to enter the data manually which can cause duplication.

Since data entities in COBie have one or more dependencies, this mistake can cause duplication and/or omission of data for specific entities. As specified by (East 2007), the handover of COBie file should occur in different phases of the project. Therefore, the data in a COBie spreadsheet increases in each delivery with new data entries and/or addition of new attributes of the existing data. Users may want to see the changes in each phase of delivery or the information sets.

Visualization of any data improves human perception by increasing the cognitive capability and reducing the complex cognitive work. The easy recognition of sensory symbols based on shapes, colours, photographic images and their meaning in the human brain, facilitates recognition of patterns without the need for pre-attention (Duncan & Humphreys 1989). It is also because the rich content of visual triggers such as colour, size, shape, position, etc. reduce the need for explicit serial process of the data. Instead, the large network of neurons in the eyes can rapidly capture the features of visual representations and implicitly pick the visual patterns with the image-based meaning of symbols. In contrast, all geometric and non-geometric data of a facility is represented in numerical and textual form in COBie spreadsheet, which increases the cognitive load of users. Processing and deriving the semantics from COBie dataset is slower than any appropriate visualized form, because the textual or numerical data is processed in a consecutive series of activities while the visual representation is processed in parallel with the perception (Ware 2012). Therefore, one of the key issues of current COBie implementation is the lack of information visualization that could enhance comprehension and reduce cognitive load.

4.2 Step.2 Define Requirements with COBie Spreadsheet

The previous section gives an overall picture of COBie and spreadsheets, and the common challenges that a user is likely to face when they are interacting with them. As a next step, to outline the problem definitions and the potential enhancements, it is essential to state the target user's role and expertise assumed in this research. The proposed development is intended for all potential users of FM data, including inexperienced and/or non-FM/O&M people who have limited to no experience with the COBie spreadsheet. These users may need to interact with and use the COBie data in different ways, including potential responsibility to interpret and generate COBie data for the later phases of the project lifecycle. The reason why we also focus on the inexperienced users is to keep the proposed development as inclusive as possible. From our ongoing and previous interactions with industry partners and collaborators, we know that in both FM and O&M domains, many professionals have expressed difficulties in understanding and using COBie spreadsheet. Therefore, we aim to define the requirements for a solution that can not only increase the efficiency of experienced users while they interact with the COBie data, but also enable lay users to access relevant COBie data. To keep the problem definition as discrete and simple to understand, we structure the requirements as a set of statements, each following the same template: “**As a user, I ... I need to/have to ...**” Based on this template, the list of requirements for targeted improvements in COBie can be defined as: **As a user, I**

- lose my focus while navigating among workbooks. **I need** a platform in which navigation is easier (interactive).
- am having difficulty to process COBie data within different workbooks. **I need to** see all the relevant COBie data and dependencies at an easy and abstract level.
- have difficulty to see the dependent information within workbooks. **I need to** explicitly see the dependencies of a specific COBie data.
- cannot search a specific data based on its dependencies. **I need to** be able to find the specific COBie databased on its dependencies.
- have difficulty in understanding the semantic links among different COBie entities. **I need to** see my search results in a simplified format.
- want to access a specific data entity and its dependencies. **I need** the functionality that does not force me to navigate repetitively.
- want to select the COBie data entity with the 3D BIM model and see selected entity's dependencies. **I need** a platform in which BIM model and COBie data is mapped with each other
- may have duplications when I enter COBie data manually. **I need** a platform that warns me for duplications and prevents multiple data entries automatically.
- have difficulty tracking the new COBie data in each delivery phase of project. **I need to** track previous and new information sets effectively.

These requirement statements were defined and validated through an iterative process in a collaborative setting. The iterative process led by the researchers, included other researchers, software developers and industry partners. More importantly, consistent with design science, the requirement definitions also evolved as the researchers conceptualized and ideated on potential solutions with respect to the current solutions. Consequently, some of the requirement statements such as “... *have difficulty in understanding the semantic links among different COBie entities. I need to see my search results in a simplified format.*” have been more concretely defined.

5. Limitation and Future Work

The reported findings are part of an on-going research, which means the requirements and our understanding of the limitations of the current COBie implementations may improve further as we refine our prototypes and solutions for a visual and interactive COBie (VisualCOBie) representation that is currently being developed and tested. The VisualCOBie platform has already undergone a few iterations and it will shortly be introduced in another publication, once additional validation and usability tests are conducted empirically.

One of the other limitations of this research was the limited understanding and usage of COBie in Finland, where the research is being conducted. This limitation is further compounded by lack of academic articles reviewing COBie. This limitation can be seen in two ways. First, the authors had to rely on feedback with only those industry partners who had familiarity and reasonable understanding of COBie from international markets. Second, considerable amount of COBie related issues were identified from discussions within the research community, as well

as from online discussion forums on COBie. Third, the lack of adequate understanding about COBie in the Finnish industry, and the lack of academic articles on COBie also prove the key point that even though COBie is being promoted as the key data format to enable the use of BIM for FM, it is yet to capture the attention of the end-user. In addition, it also means that this paper raises a timely issue, bringing attention in the academic community towards COBie and its strengths and weaknesses in its current form.

6. Conclusion and Discussions

The main contribution of this paper is the evaluation of COBie from the perspective of end-user interaction, usability and functionality; and defining the requirements for improvement of COBie from usability perspective. The findings presented in this paper are part of an on-going research aimed at developing an interactive and visual solution for COBie data. Based on a critical review in a research that adopts design research methodology, the main limitations of the COBie standards are traced back to its dominant representation as a set of spreadsheets, with large amount of textual data. Consequently, the usability issues associated with large spreadsheets such as getting lost and keyhole effect automatically emerge with COBie as well. In addition, similar to many other situations where spreadsheets are used as collaboration tools, COBie spreadsheets are also expected to be filled and contributed to by various actors, and at various stages of the project lifecycle. This collaborative aspect creates further usability challenges, because users need to track the changes and additions to the data, leading to issues such as version management and duplication.

Based on the review, it is evident that the widespread use of spreadsheets, their low usage barrier, and their ease of information gathering and editing capabilities, were the dominant reasons for spreadsheets being the primary representation for COBie data. At the same time, it appears that one of the key reasons for the usability challenges associated with spreadsheets, and hence with COBie, is the lack of mechanisms to explicitly map and visualize the dependencies between the different data entities spread across different parts of the spreadsheets as well as across different workbooks. Thus, it can be argued that the information management issues and process view of data integration were the key factors considered so far in COBie development, while the usage and usability factors have so far remained overlooked. This problem of ignoring the usability and end-user perspective is not limited to COBie, but it is a typical trend in construction technology related developments. Not surprisingly, many of these technological developments fail to reach the desired rate and desired level of adoption, because users find them difficult to use, despite their technical capabilities. Singh et al (2011) make similar arguments, emphasizing that the support technical requirements that improve usability and focus on the end-users should be considered in parallel with the operational technical requirements, and not as separate add-on activities. Therefore, this research puts usability and the end-user perspective at the core of the chosen design science methodology, and such an approach is directed towards addressing the industry feedback and commonly reported grievances about the complexity and lack of understanding about COBie.

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Walk the Talk: Creating a Collaborative Culture in an Activity-Based Workplace

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Abstract

Creating organisational change by moving in to new premises has recently gained increased interest and attention. Business driven and process oriented relocation strategies – continuing after the relocation – enable organisations to re-design both space, current business practices and corporate cultures. The question, however, is whether such projects succeed in the end of the day. This paper explores how the process of moving in to a new workplace concept strategically may be used to change an organisation's collaboration culture. This is studied from the perspective of cultural artefacts, change management as well as physical and structural change. The discussion builds on semi-structured interviews with 65 employees from a Norwegian organisation. The findings indicate that the physical change, supported by process activities and change management actions, paved way for a cultural change towards more collaboration amongst employees as well as increased collaboration across hierarchical levels. However, misalignment in some areas between the new concept and existing cultural assumptions, values and norms, also restricted the organisation in fully achieving the intended ends. Therefore, the study highlights challenges and issues to overcome in order to use facilities as a tool for strategic change. The findings further underline the importance of creating a continuous change process, extending beyond the moving process itself.

Keywords: Artefacts, Change management, Workplace concepts, Activity-based working, Socio-materiality.

1. Introduction

Succeeding with organisational and cultural change is a challenging task (Schein, 2004; Balogun, 2006). Often advocated spatial efforts to enhance organisational collaboration, especially through open workspaces, common pathways and increased sightlines have also been found to have their limitations and sometimes fail in achieving the intended ends (Pepper, 2008; Becker et al., 2003; Rylander, 2009). Becker et al. (1994) however argue that business driven and process oriented relocation strategies – continuing after the relocation – may better enable organisations to re-design both space, current business practices and corporate cultures. It is furthermore becoming more and more recognised that in order to succeed with strategic change, different organisational factors need to be aligned with the new strategy. This approach recognises that the physical workplace is an integral part of the organisational structure and culture. Interweaving organisational structures and culture in organisational change processes, may thus provide organisations with greater opportunities to achieve transformational change (Becker et al., 1994; Schriefer, 2005; Miles, 1997). In this perspective, the organisational structures or space may function as a catalyst for change (O'Neill, 2007; Inalhan and Finch, 2012; Allen et al., 2004) or the other way around, be used in order to reinforce and stabilise the change (Bate et al., 2000). However, in execution of organisational change strategies, Miles (1997) argues that organisations often start up by changing structures and infrastructures. Changing people, culture and core competencies generally require a longer process. This article aims to explore the culture-structure relationship in an organisational change process.

1.1 Cultural Artefacts and Organisational Change

When executing a strategy, managers must handle a number of different factors, organisational culture being one of the most important (Balogun and Johnson, 2004; Schein, 2004). According to Schein (2004), an organisational culture consists simultaneously of three reciprocally connected levels: (1) *artefacts*, (2) *espoused believes and values*, and (3) *taken for granted assumptions*. The three levels are based on the degree to which the phenomenon is visible to the outsider. Taken for granted assumptions being on the lowest level and artefacts on the highest – most visible level. Artefacts, physical and/or non-physical, are all organisational phenomena that one may see, hear and feel. Espoused values and believes, as well as assumptions have been found to have a significant role in determining employee perspective, adaptation to and use of space (Hirst, 2011). Although not always visible to the observer, they are expressed and shared through social processes (Schein, 2004). Artefacts are furthermore environmental signs conveying information about social orders – thereby influencing and constraining social actions (Baldry, 1999; Bechky, 2003). Therefore artefacts are often considered as a form for organisational message (Cooper et al., 2001; Allen et al., 2004). Klingmann (2007: 259) argues that architecture is “a visual symbol for the expression of a corporation’s culture and personality”. Thus, space may be used as a cultural creator – forming and reinforcing the culture (Schein, 2004; Steele, 1973).

Space and artefacts are also socially produced and culturally constructed – leading people through embodied experiences in the form of feelings, emotions, and memories (Kornberger and Clegg, 2004; Taylor and Spicer, 2007; Dale and Burrell, 2008). Language and the way we talk about space further construct spatial experiences, not only steering our interpretation of space but also forming actions, behaviour, interpretations and judgements (Airo et al., 2012). As people make subjective judgements of physical environments, the experience and judgement of a particular place may not simply be reduced to strategies, intentions, managerial and architectural plans (Ropo et al., 2013). For example, Rylander (2009) found that project managers, designers and users, through their different understandings, perspectives and experiences apply substantially different meanings to a new workplace concept. In line with the concept of affordances developed by Gibson (1979) actions are formed not only by the space and its artefacts, but also by social processes informing people about space and its meaning. In this perspective, artefacts do not determine behaviour but rather provide cues of socially accepted behaviour in a particular context (Värlander, 2012; Gibson, 1979).

Artefacts are furthermore commonly used to lead, manage and divide people and support hierarchies (Vaasgaasar, 2015; Taylor and Spicer, 2007; Grenness, 2015; Baldry, 1999). Building on such argumentation, leadership may be formed without the presence of the leader, this through artefacts providing the observer with information forming actions and the meaning-making process (Ropo et al., 2015; Greenlees, 2015). Size, location and furnishing of individual offices are especially often used for this purpose (Muetzelfeldt, 2006; Baldry, 1999). Edenius and Yakhlef (2007) also argue that spatial markers and symbols are useful in order to formalise rules. However, when spatial change is made without addressing the other cultural dimensions, unintended changes within the political culture of the organisation may occur (Markus, 2006). Ultimately, if new artefacts are in contrast to other artefacts and/or existing assumptions, values and norms an equivocal message may be created, leading to misinterpretations and possibly unintended outcomes (Schein, 2004; Gibson, 1979; Pepper, 2008).

1.2 Leadership and Cultural Artefacts

Space in it self does not hold meaning. Meanings attached to space is rather created, changed and defined by time and former experience. The same process goes for culture and leadership, this as leaders create culture, and culture defines and creates leadership (Schein, 2004). Leadership is, however, not only a social phenomenon, this as “leadership is being shaped, modified and constructed by material workplace arrangements” (Ropo et al., 2015: 2). The ways in which leaders and organisational members act, behave and use space – such as the CEO’s position at the head of the table – are in fact cultural artefacts, affording people and their actions (Schein, 2004; Gibson, 1979). Thus, space is connected to the way organisations are used to seeing and regarding leaders. The general trend to move from a ‘hierarchical’ control system to ‘horizontal’ network structures, is however changing the role and view of leadership (Dale, 2005). In this perspective, transition to open, transparent and activity based workplaces, where leaders and employees work side-by-side, may influence new cultural assumptions (Blakstad, 2015), decrease boundaries and hierarchies (Värlander, 2012), and support values of equality amongst organisational members (Grenness, 2015; Bakke, 2007). Nevertheless, ownership of

space is still deeply connected to assumptions such as status, importance and value. Transition to a non-territorial workplace without owned space may for some imply lower status, lack of interest in employee comfort (Hirst, 2011) and even signal that everyone is replaceable (Bakke, 2007). Leaders that are forced to give up their office may thus feel that their personal status is threatened (Elsbach, 2003).

As change in cultural artefacts challenge existing norms and assumptions, this may result in strong emotional reactions and even resistance. To cope with the new workplace, organisational members need to ‘unlearn’ old values and norms and ‘relearn’ new ones (Grenness, 2015). Building on the argumentation by Schein (2004), placement of oneself in relation to others and to different functions symbolise factors such as membership, status and social distance. Here, leader’s actions, functioning as cultural artefacts, are pivotal in forming values, behaviours and norms (Balogun, 2006). Especially top-level management actions and belief in the value of the change have been found to be pivotal in succeeding with organisational relocation strategies (Bakke, 2007; Schriefer, 2005). Miles (1997) further argues that successful change managers are those who take any opportunity, no matter how trivial, to demonstrate and act the change. This may constitute a new corporate storytelling, which may act as an effective support mechanism for the change processes. Behavioural stories may function as a means of guiding employees in their everyday decision making processes, help employees to understand the rationale for change and be a tool for communicating a message (Stegmeier, 2008). This is a continuous process where the ‘change agent’ assists others in the transition from the present state to the desired state (Becker et al., 1994).

Schein (2004: 170) argues that, “shared assumptions arise only over the course of time and common experience”. To this end, actions and use of space may function as meaning-making triggers contributing to organisational learning (Balogun, 2006) and through ‘learning by doing’, activities gradually form new sets of rules and norms (Steele, 1973). The open office environment daily offers opportunities to support the change effort and “lead through own appearance and action” (Vaasgaasar, 2015: 80). In the transition to new workplaces, managers need to ‘walk the talk’ – explaining the new strategy through their own actions. This is an iterative process where managers often are challenged, this as the transition itself may lower their status and force them to start to earn status in other ways than through physical artefacts and cues (Grenness, 2015). Higgins and Mcallaster (2004), however, observed that top managers generally do not perceive the links between changing strategy, changing culture, and changing cultural artefacts. As assumptions are often taken for granted, managers are also seldom aware of their own assumptions and what effect this has on the change process (Schein, 2004). If manager behaviour is not in line with the new strategy this may become a hindrance, allowing employees to act on old values and norms (Balogun, 2006; Balogun and Johnson, 2004).

2. Methods and Case

The empirical material draws on semi-structured individual and group interviews with 65 employees from a Norwegian professional service network provider. The organisation provides services within fields such as auditing, consulting, financial advisory, risk management as well as tax and legal. Participants were purposely selected from the different business areas and levels within the organisation, this to include organisational members with different roles, work tasks and responsibilities. In between interviews, use of the workspaces was studied through unstructured observations. Brief informal discussions with approximately 40 employees were also conducted during the study. The study was conducted in three main phases approximately 1,5 years after the transition to the new headquarters. Data from each phase was analysed before moving onto the next phase. To identify differences and similarities between the business areas, data from the units was furthermore coded and analysed separately. The focus was, however, on cross-unit analysis, thus the reported findings cut across all units, unless otherwise stated.

The change started early in the process with a new organisational strategy. The intention of the relocation was to set *“a new standard for collaboration”*. The strategy focused on better collaboration and utilisation of knowledge within and across the different business areas. The organisation wished to build on the newly implemented strategy, and by transition to the new building, reframe the culture-structure relationship. The new concept was activity-based, supported by free-seating and clean-desk principles. Due to high resistance towards free-seating, confidentiality requirements and other practical needs, some departments were allowed to have individually owned workstations. The different zones range from silent- and semi-silent zones, project areas, meeting- and collaboration rooms to open centrally located areas for social interaction. Signs hanging from the ceiling mark each zone. The signs have a colour, a symbol and a short description – explaining and giving cues to what activities are appropriate within each zone. The main focus was on facilitation of interaction processes, as explained by one manager: *“It is important that the new building facilitates employee interaction. The building cannot create interaction by itself, but it may facilitate interaction”*.

3. Findings

3.1 Collaboration within Departments and across Hierarchies

Where free-seating and space-sharing structures were implemented, employees reported that internal communication and collaboration had increased. Work in the new office was described as “more social” and collaborative than in the old office. Several employees commented that, as they often worked close to others they had gained a larger internal network and also befriended new colleagues. As told by one of the employees: *“You come in contact with people that you normally don’t come in contact with”*. *“I’ve got new friends here”*, comments another. Several experienced that this eased seeking help from others. Many also remarked that they had gained a closer connection and more knowledge about different areas within their own department. Working in open workspaces was furthermore reported to help streamline work processes.

Perceptions, however, varied between departments. In departments where individual workstations had been implemented some managers and partners seemed to perceive an increase in collaboration, however, most employees did not perceive any noticeable increase – rather in some instances a decrease. At these locations several employees stated that, as one were afraid to disturb others, one did not ‘dare’ to talk in the open landscape. Thus a ‘whispering’ culture was created at several areas. As employees became more used to the open landscape, this code of conduct gradually changed towards more interaction at most areas. Nevertheless, some groups still struggled with social interaction at the time of the study. At these areas the norm and assumption was that work processes were mainly conducted as individual tasks, thus the workspace ought to be quiet allowing for individual concentration. This sub-cultural norm and the high value placed on individual work also effected interaction within adjacently located groups. In the words of one employee: *“I find it useful to throw out a question to colleagues in an open workspace, however, I don't feel comfortable with doing that here”*. Some, especially lawyers, further stated that, due to confidentiality requirements it was challenging to discuss work related issues in the open landscape. A perception, however, not shared by all – especially not by partners and managers. Contrarily, these groups argued that confidentiality was no problem as long as one followed the organisational confidentiality ethics and guidelines and also used the available collaboration rooms. Nevertheless, some used individual work processes and the confidentiality requirement as legitimate claims for having own offices.

To facilitate random encounters and collaborative work processes, each floor had a centrally located coffee area, furnished with lounge furniture and high-stand tables. Despite this and the signs, explaining the purpose of the zone, these areas were mainly seen to be unused after the transition. In the beginning, many believed that spending time in these areas was perceived as “being lazy” or “non-efficient”. As one employee stated: *“As a consultant, you charge the customer by the hour. You need to be efficient. Hanging out in a sofa may give the wrong impression”*. To change such assumptions, some managers hung additional signs, emphasising the value of collaboration and informal interaction. To ‘walk the talk’ some further started to spend more time working and collaborating from these areas. At the time of the study, use of these spaces had remarkably increased. To facilitate team collaboration, open landscape ‘project areas’ were also located adjacent to the informal areas. Also, these areas were mainly unused after the transition. The general openness and caution of sharing sensitive information to others seemed to restrict employees from using these areas. Furthermore, as these areas also were new functions with which employees did not have any experience, some reported that they were insecure with regards to what kinds of work processes and activities that were appropriate or allowed. However, at the time of the study, these areas were highly appreciated and believed by many to be crucial for collaborative working and creating ‘workflow’. Being able to share documents on screens on the walls and spread out work material were seen as especially important. Several employees also commented that the project places were efficient in sharing knowledge and informing others – *“the people just passing by”* – about on-going projects.

The former workplace concept had a hierarchical workplace structure with individual offices mainly assigned to seniors, managers and partners. Going from this to a workplace structure where members from the different levels of authority shared workspaces created challenges as

well as benefits. The new workplace facilitated a flatter structure allowing organisational members at different levels to sit ‘side-by-side’, thus collaboration across hierarchical levels was seen to have been improved. Many also described the organisational hierarchy as being flat, especially with comparison to similar organisations outside the Scandinavian countries – an observation in line with research on Scandinavian workplace cultures (e.g. Grenness, 2015). Arguably, the new workplace was perceived to better reflect the low-hierarchical structure. Transitioning to a new workplace also changed the hierarchical map of the workplace. In the former workplace, free-seating had been implemented in one department. However, informal rules and behavioural norms, grounded in the hierarchical structure and culture, defined where different organisational members were *expected* to find a desk. As such, areas for managers, partners, seniors and newly employed had been created. With few exceptions, these sub-groups had disappeared during the transition in to the new office. The exceptions were mainly related to areas where members from the top-level management situated themselves. As a result others seemed to avoid situating themselves at these particular places. Nevertheless, as most top-level managers situated themselves adjacent to the informal areas, they also – through their choice of place – invited employees to engage in interactions by the ‘manager’s’ table. Employees’ perception was that when top-level managers and also other managers worked from these areas they simultaneously signalled that they appreciated a low-hierarchical culture and were open for inquiries and interactions. Several employees also reported that knowing partners and managers spatial patterns both eased finding them and also eased knowing when they were available for inquiries. Moving managers and partners from assigned offices were, however, by some seen to create higher boundaries and challenges in terms of communication. Previously, the sign of an open door functioned as a cultural artefact informing organisational members of the person’s availability. Uncertainty of whether the persons were actually available for questions or having to ask them to join in for a conversation at another location seemed for some to make the threshold for making contact somewhat higher. Few managers and partners on the other hand perceived this to be a challenge, rather stating that inquiries had increased – however, becoming shorter and more efficient. Managers and partners also perceived that working next to others facilitated ‘workflow’, tacit knowledge sharing and sharing of sensory experiences.

3.2 Collaboration Across Departments

In the old building, a centrally located staircase connected the different departments and was described as a place where people ‘bumped into each other’. The new office – higher and narrower in structure – seemed to decrease spontaneous encounters and therefore also collaboration between organisational members from different departments. However, areas such as an in-house coffee bar, the previously mentioned social and project areas, and a project area accessible for the whole organisation on a separate floor, created substitute areas for spontaneous encounters and collaboration activities. Employees who spent more time at these locations did not, to the same extent, share the view that spontaneous encounters or collaboration across departments had decreased. Contrary, these employees believed that the new facilities provided better locations for more relaxed and ‘deeper’ conversations and interactions. Especially the in-house coffee bar functioned as an area where organisational members from different departments were seen to interact with each other. Stated by one

employee: *“I went to work at the coffee bar one time, and a person that I just had sent a mail to came in. So we sat down and had a brief conversation”*. Additionally, internal staircases connecting some of the floors were found to benefit spontaneous interactions.

Nevertheless, the view shared across the organisation was that knowledge of and connection to other departments had diminished. Many assumed that, as they did not see members from other departments as much, they did not collaborate as much. The ultimate effect is, however, questionable, as most employees perceived that their own work had little or nothing to do with other organisational departments. However, in instances where specific projects were held across different departments, employees were seen to move around more, also working from multiple floors. The sharing structure and freedom of movement within the building did in this perspective offer opportunities for work in and between the different departmental floors. The perception of less cross-departmental collaboration may further be related to the fact that the organisation since the transition had experienced a significant growth. Some employees expressed that this had resulted in less communication and fewer instances of informal group meetings – also within their own departments. In this perspective, some artefacts from the old workplace had also been lost. For example, the staircase in the old building facilitated weekly status meetings, also called ‘stair-meetings’. Although these meetings still occurred, they were not as frequently held and no longer perceived as an important cultural artefact. Ultimately, some expressed a loss of a former ‘homey’ culture and feared that as the organisation continues to grow this would continue to affect the organisational belonging.

3.3 Time and Management

Prior to the transition, workshops and process activities were conducted with the aim to discuss issues such as, what ‘a new standard for collaboration’ meant for each department. The general answer to this question was that: *“The new standard for collaboration is something we develop together over time”*. As previously described the patterns for socialising, collaborating and communicating had since the transition gradually changed. When moving to the new workplace many seemed to categorise the workplace into primary, secondary and tertiary workstations. The ‘own’ work desk was perceived as the primary workstation, meeting- and project rooms functioned as secondary workstations and informal meeting places were perceived as tertiary workstations. As the different cultural dimensions gradually changed, many started to regard the former secondary and tertiary workstations more as primary workstations – ultimately considering a multitude of workstations as being suitable for conducting different work processes. A ‘mentality change’ was also seen to have happened amongst some groups of managers and partners. Prior to the transition, several of these groups requested a separate area assigned to them, a request, however, turned down by the management as they believed it to be against the strategy and the desired collaborative culture. After the transition none of the interviewed managers and partners requested such an area. However, at one department the free-seating structure was gradually redefined into one area for managers and partners and another area for ‘others’. This was not a formalised structure, rather as one employee put it: *“When managers and partners always choose a place in the same area, no one else dare to sit there”*. Thus, there were still instances where managers’ and partners’ behaviour maintained a

hierarchical structure, thus the social relationships across hierarchical levels were not yet fully developed. As a result, behavioural artefacts restricted development of a collaborative culture.

Statements and actions given by specific organisational members were further seen to influence organisational members' assumptions and norms. Early in the process, the CEO and the top-level management informed the organisation of the intention and vision for the new workplace concept. Doing so they also stated that they would work in the same workplace, with the same sharing principles as everyone else – adding that anyone that wanted something else could come and talk to them. Few came. Since the transition the CEO and the top-level management have kept their words, working according to the free-seating structure. Also other managers and partners commented that they felt obligated to be early adopters and give good examples for co-workers. This question was also raised in the process where managers and partners were told that if they didn't feel that they could lead the change, they should at least try not to be openly negative. Nevertheless, few partners and managers perceived that there had been any focus on them as regards to being 'change agents'. Although managers' behaviour was found to be important for 'leading the change', few regarded their actions in the office to be of any importance. Several organisational members, however, commented on specific managers, their actions and how this had been important for creating a 'new standard'. Placing oneself in a highly visible area, working from different locations and actively participating in the everyday work environment were by many seen as important cultural artefacts. Contrary, when managers and partners seemed to do the opposite – creating own areas, choosing the same place every day or removing them selves from the work environment – employees often reacted negatively, arguing that they should at least try to lead by example and try the concept. As a result, some groups of employees also had a tendency of breaking the concept rules, creating sub-groups and their own rules. Noticing the importance of the process and management actions, some managers emphasised the value of putting enough resources into the process: *“If you really want to create a transformational change then you need to put resources on changing minds”*.

4. Discussion

Implementing a new workplace concept with an open shared space structure did in many ways facilitate “a new standard for collaboration”. However, creating a new standard for collaboration did not only require a physical change but also a change within the other cultural dimensions. In line with the argumentation by Schein (2004), the findings illustrate that where a change in assumptions, values and norms had not happened, no remarkable change occurred or unintended outcomes emerged. As for the departments where individual work was valued higher than collective work, the new spatial artefacts worked in direct contrast to the existing cultural norms and values. As such, employees also resisted the new workplace, arguing that it did not support them in meeting the intended ends – findings also in line with Grenness (2015), Rylander (2009) and Pepper (2008). In this perspective, the new artefacts in themselves did not have the power to 'break through' and change the other cultural dimensions. However, at departments where team and project work processes were valued higher, change was more seen as an alignment and modification of the physical workspace to better fit the culture and the already implemented strategy. To this end, the workplace and its artefacts both paved way for the

change as suggested by O'Neill (2007), Inalhan and Finch (2012) and also Allen et al. (2004), but also, as suggested by Edenius and Yakhlef (2007) and Bate et al. (2000) functioned to formalise rules which further stabilised and reinforced the change.

As suggested by Schein (2004) and Hirst (2011), employee assumptions, values and behavioural norms guided and formed adaptation to, use of, and satisfaction with the new workplace. Old assumptions such as: the standard desk is the primary workstation, and that fun and informal conversations are not an important part of core work processes did thus create barriers for change. The fear of 'sharing information' and the pending confidentiality discussion at some departments represented a 'confidentiality culture' where information should be 'guarded' and properly handled by the employee. During the transition, the value of knowledge sharing, however, became more and more prominent at most departments than the value of confidentiality. As managers also took a more present part in the landscape, breaking down the hierarchical boundaries, this further supported the non-verbal message and ultimately the change initiative. The change in values influenced both use and the ways employees related to and talked about space, findings also supported by Airo et al. (2012). By time, the new concept started to work more in harmony with a newly formed organisational collaborative culture – stressing the fact that structure and culture must co-evolve (Bate et al., 2000). The process here was one of continuous learning, changing and learning from changing. The process of 'unlearning' and 're-learning', as emphasised by Grenness (2015), may in this perspective be seen as an iterative process where old and new values and assumptions are tested against each other. This in turn, stress the need for a change management process extending beyond the transition itself, as also emphasised by Becker et al. (1994).

As a new set of assumptions, values and norms gradually was created at some departments, and especially as some hierarchical structures were broken down, employees also got more freedom to start to explore the new concept. However, the fact that the project was seen to be finished soon after transition and that no formal structures were developed to follow and further steer development of the original vision, may also have hampered goal achievement. The focus on spatial change as a tool for affecting cultural change, also contributed to the creation of a rather rational deterministic thinking. Supporting the argumentation by Värlander (2012) and Rylander (2009), the deterministic perspective was found to be challenging and partly unfruitful in achieving the intended ends. The additional cues and behavioural artefacts implemented by some managers and partners may in this perspective have been crucial for achieving the intended ends. However, as some managers' and partners' actions and use of space also reinforced hierarchical levels, the boundaries within the organisation were not eliminated – rather redrawn in the new office. In line with Becker et al. (1994), Balogun (2006) and Miles (1997) corporate managers' and partners' actions strongly defined the value of the new cultural artefacts as well as the meanings employees assigned to the different spatial solutions. As such, sub-cultures and norms became visible in the open workplace structure. The lack of physical boundaries between groups and members, also allowed for cultural norms to transmit and travel between groups. Due to the complicated interaction between the spatial workplace and the organisational identity, as well as the different identities within different sub-group, achieving the intended ends were seen to require as extended process. Thus, the study stresses the need not

only for a continuous iterative change management process but also the need for applying a set of different tools, measures and strategies within the overall strategy.

5. Conclusions

The article illustrates that use of a new workplace concept to effect cultural change is dependant on an alignment between spatial artefacts and other structural and cultural dimensions. If an organisation attempts to utilise a relocation process for strategic change organisational aspects, cultural values, norms and assumptions needs to be addressed and handled as an integrated part of the strategy. This will ultimately lead to a situation where space and culture may co-evolve into alignment. In a physical transition it is further important not only to renew critical cultural artefacts, but also to maintain those that already support the new strategy and the desired culture. In accordance with the perspective of space as socially constructed, management and sub-groups' use and relation to the concept were also found to be important in shaping new cultural assumptions and norms. Arguably, implementation of new workplace concepts with the intention to affect and change cultural dimensions need to be handled as an on-going process, continuing after the relocation and also supported by management action and behaviour as well as supported by a multiple set of integrated tools and strategies. Organisational members' appropriation of space and buildings are furthermore significant in achieving high levels of building usability. Addressing the socio-material relationship in research as well as in the development and implementation of new workplace concepts may provide the building sector with more knowledge with regards to buildings' usability and strategic use of the built environment.

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How employees value the support of activity based and traditional work environments

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Abstract

New Ways of Working (NewWoW) are popular, both for increasing employee and organisational effectiveness and attracting new talent. As Corporate Real Estate management (CREM) is responsible for delivering a supportive office environment for employees and the organisation as a whole, they must align by providing a work environment that aims for employee satisfaction, increased support of productivity and other added values. This is often done through introducing the shared workspaces and facilities of activity based working (ABW). However, lack of proof of advantages of such work environments is feeding a more reserved attitude towards NewWoW. This paper aims to provide evidence for differences between traditional and ABW environments in workplace support of organisational goals as perceived by employees.

Online questionnaires (2010-2014) from the Leesman Database amongst 47,913 office employees (mainly Western European organizations) were analysed for employee opinions on workplace support. Respondents were split in two groups based on their workspace: ABW or a traditional, dedicated seat. Statistical tests of differences between both groups provided insight in five types of added value.

The ABW employees were more positive on all added values included in the questionnaire and the support of their workspace for important activities. Also, they were more satisfied in general and with most of the individual features and facilities of their work environment. Only satisfaction with their desk, chair, personal storage, phone equipment, desk/room booking systems, in-office network connectivity and the ability to personalise was lower than the employees working at dedicated seats. The design of the ABW workspace had a more positive (perceived) impact on culture, corporate image and environmental sustainability. Further, they agreed more with statements that the design of their organisation's workspace contributes to a sense of community, creates an enjoyable environment to work in and enables them to work productively.

The results from this analysis provide CRE managers with proof for implementing ABW environments in their office portfolio. Not only did employees that work flexibly feel more supported in their work by their workplace, they also felt that it better supports general strategic organisational goals like productivity, corporate image and sustainability.

Keywords: added value, work environment, employee preferences, chi square tests, independent samples t-tests

1. Introduction

The workplace is said to be a strategic tool for organisations, but there is still little evidence to show how and in what contexts (Kampschroer and Heerwagen, 2005; Blakstad et al., 2009; Steen and Markhede, 2010). Therefore, for many organisations it is still mostly a costly resource for which cost reduction is the main aim (Gibler et al., 2010). However, corporate real estate (CRE) managers at contemporary organisations increasingly try to work with a workplace strategy aiming at a more optimal cost/benefit ratio (Jensen, 2009; Pullen et al., 2009). For benefit they look at the added value of the physical work environment for employees and the organisation as a whole. Jensen et al. (2012) detected six different types of added value of CREM in their review of the literature:

- Use value: quality in relation to the needs and preferences of the end users;
- Customer value: trade-off between benefits and costs for the customers or consumers;
- Exchange value: economic trade-off between costs and benefits;
- Social value: connecting people;
- Environmental value: environmental impact;
- Relationship value: experiencing high-quality services.

While exchange value lies fully within reach of the CRE manager, the effect of the other added values is (partly) indirect and thus cannot be isolated from other variables, which makes it harder to prove the relevance (De Vries et al., 2008). These added values do not only have an effect through the real estate itself but also through the employees (use, social and relationship value) or clients and society (customer and environmental value). As employees and clients are important for knowledge organisations, a positive influence on this should be highly valued by their corporate management. Unfortunately, measuring these indirect added values is often troubled by a lack of outcome indicators, making it hard for CREM to show proof. As Feijts (2006) suggested that the indirect effects explain the majority of performance changes, this deserves more research.

With the rise of strategic CREM, many companies have redesigned their buildings and workspaces to influence employees' attitudes and behaviours (Robbins, 2003). Large companies are increasingly moving towards new ways of working practices (from here on called NewWoW) (Inalhan, 2009) and the so-called activity-based office concept. But evaluating whether these designs have succeeded in their goals of adding value is difficult and not done much yet (Pullen, 2011; Maarleveld et al., 2009; Laihonon, et al., 2012). Particularly little is known about the consequences for employee attitudes and well-being (Ten Brummelhuis et al, 2012; Peters et al, 2014). Therefore, this paper focuses on the question how contemporary office design relates to organizational performance, from the viewpoint of the office employees working in it.

The next section provides a short overview of the literature on the contemporary work environment and different added values it might have. Then the research approach is explained,

which is based on statistical analyses of questionnaires among 47,913 employees from 115 different organizations. In the results section the findings are described, followed by a discussion and recommendations for further research.

2. Contemporary work environments

Despite of the hype and well-known terminology, a survey taken by Van der Meulen (2012) showed that 67% of the organizations that are orientating themselves on NewWoW implications do not know exactly what NewWoW encloses nor what benefits it could provide. Half of the respondents even had negative associations with it. The coverage on NewWoW in magazines and journals is often either very positive or very negative (Pullen, 2011). This has led to a more reserved attitude of some organizations towards introducing NewWoW (Baalen et al., 2011) and the effort to convince management to do so, has increased over the years (Van der Meulen, 2012).

The term Activity Based Working (ABW) has become a widely used expression for different office concepts that support NewWoW and is regarded as one of the most advanced concepts (Ross, n.d.). These concepts have in common that all users, from employee till general management, can choose to work at all available workspaces and collective facilities and where nobody is allowed to claim their own workspace. ABW offices offer a variety of different types of workspaces aimed at supporting different activities. So there are no dedicated seats and people are supposed to choose different workspaces throughout the day, based on their activities at that moment. Besides exchange value through cost reduction (a decrease of m²'s), added use value through increased employee satisfaction and productivity are important goals of organizations implementing ABW (Van der Voordt, 2004; Baalen et al., 2011). A positive image and as a consequence attraction and retention of scarce personnel and clients, more flexibility and environmental impacts (CO₂) have also been mentioned as additional aims of the ABW environment (Ruostela et al, 2014; Blok et al, 2011; Van der Voordt, 2004).

But expectations and realizations of NewWoW do not always coincide (see Figure 1). In a study of Baalen et al (2011) among more than 250 organisations, all aims of implementing ABW, except more flexibility, showed a lower achieved effect than the original expectation. While the effects on the organisational process (flexibility, costs) largely matched expectations, effects on employee output (productivity) and organisational image towards their employees (employee wellbeing, satisfaction, image) lagged behind. In a before/after study questioning employees that moved towards an ABW environment, Blok et al (2012) also showed no higher appreciation of use value (satisfaction and the suitability for work tasks) nor social value (collaboration with other employees). Top-down implementing new working conditions is said to be insufficient to achieve positive work outcomes, as it might not change the actual behaviour at the office and could even be a source of stress (Peters et al, 2014). So it seems important to know in more detail what employees with dedicated seating think of their work environment versus the ones working in an ABW environment to discover which added values are perceived by them.

Realised and expected NewWoW effects

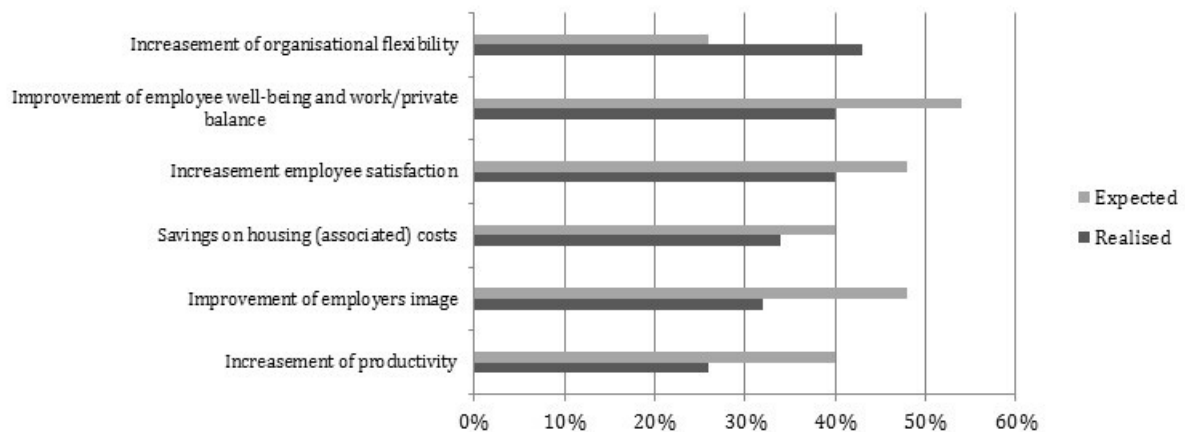


Figure 1: Realised and expected NewWoW effects (Baalen et al., 2011)

3. Research approach

As this paper focuses on employee opinions about the work environment, an existing large, multinational dataset of employee questionnaires was used. The questionnaires have been developed and collected by Leesman ltd (from 2010 up to February 24, 2014). Their online surveys of employees question various workspace aspects and some general data on the respondent (e.g. age, gender, position etc.). Average response rate to the Leesman survey is 64%. The so-called convenient sample taken for this paper included 47,913 employees from 115 different organizations divided over more than 370 locations (average 369 employees/location).

Respondents mostly worked at organizations in Western Europe that approached Leesman to survey their employees. Although the database contained respondents from 22 countries spread over all continents except Asia, 59% of the respondents work in the UK and 22% in Sweden. The other 19% had a very diverse origin. The organisations belonged to many different sectors,

both profit and non-profit. Because of the non random sampling method the results were interpreted with care. However, the large number of organizations and employees included supported generalizability to Western European Offices.

From the complete set of 47,193 respondents, those who pointed out to spend <50% of their time at the primary office were not taken up in the sample (= 4,122 respondents or 8.6%). This guaranteed that respondents who only visit the office for short periods of time did not influence results. The rest was split in two groups (ABW flexible environments versus traditional environments with dedicated seating (TradWoW)) based on the work setting they indicated to work in most of the time. TradWoW employees worked at a private office, cubicle, technical area (e.g. drafting table), shared office with own desk, own workstation in open plan area or other. ABW employees mostly worked at a pre-booked hoteling or hot-desk, shared team table, informal work-setting, flexi/shared workstation or touchdown area. The NewWoW group obtained 6,243 (14.2%) respondents and the TradWoW 37,557 (85.8%) respondents.

To look at the employees' opinion on use value, the following survey questions were used:

- Opinion on importance of workspace design (on a 7 point scale of -3 to 3);
- Perceived support of activities that were important to them (For 21 different office activities the respondent was asked to state whether it is an important activity for them (yes/no). If yes, the respondent was asked to rate support of this activity by the workspace design on a 6 point scale of -3 to 3, without 0. Support of all activities was added up and averaged);
- Satisfaction with 31 features and fifteen facilities of the physical work environment (For each feature and facility the respondent was asked to state whether it is important (yes/no). If yes, the respondent was asked to rate satisfaction for his or her current workspace (on a 5 point scale of -2 to 2). A respondent indicating to find a certain feature/facility not important was not asked about satisfaction with this aspect. This is considered to be neutral satisfaction (=0) in the further analyses. Satisfaction with all features and with all facilities was also added up and averaged to get total scores);
- Opinion on workspace design enabling them to work productively (on a 7 point scale of -3 to 3)

For customer value, the questionnaire contained one question on the impact of workspace design on corporate image. Exchange value was disregarded as employees do not have insight in workplace costs and how efficiently these are managed. Social value was studied with questions on workspace contribution to workplace culture and a sense of community at work. Environmental value was measured by the perceived impact on environmental sustainability. Relationship value was measured with questions about whether the environment is enjoyable to work in and whether they are proud to bring visitors. All these questions were asked to be rated on a 7 point scale (of -3 to 3).

To test differences between both groups, either χ^2 - or t-tests could be used. As the 7-point scales are quite large, one could argue that t-tests on the group means are allowed, although it is not a fully continuous scale. But as several of the variables did not show a fully normal spread (most lean towards the positive side of the scale), χ^2 -tests were used to test significance of differences

observed for most of the added values. For the use value, new variables were calculated in SPSS, namely the mean satisfaction with all features and with all facilities of the work environment and the mean support of important activities. These were tested with t-tests to look for differences between both groups, as these were continuous variables with a normal spread. All statistics are visible in Table 1.

The flexible and the dedicated seating group did not show significant differences with regard to gender (58% male, 42% female), age (normal distribution), part time employees (6%) or time working at this organisation. Only on the country of residence, the groups showed significant differences ($\chi^2(23, N=43791) = 2817.6, p = .000$). The NewWoW group consisted of 75% UK employees (vs. 47% in TradWoW) and employees from the Netherlands, Germany, France and Sweden, so only European countries. In the TradWoW group the Swedish account for 24% of the group (vs. 8% in NewWoW) and several other non-European nationalities were also present.

Table 1: Statistics on all the added values

	<i>statistics</i>			
	<i>n</i>	χ^2 -value	<i>t</i> -value (equal variances assumed)	<i>p</i> -value (* = sign.)
<i>use value</i>				
<i>importance workspace design</i>	43516	28.3		.000*
<i>support of important activities</i>	43550		-12.0 (no)	.000*
<i>satisfaction with all features</i>	43561		-9.1 (yes)	.000*
<i>satisfaction with all facilities</i>	43561		-23.4 (no)	.000*
<i>enabling to work productively</i>	43524	89.5		.000*
<i>social value</i>				
<i>contribution to workplace culture</i>	43519	360.8		.000*
<i>contribution to sense of community</i>	43521	144.8		.000*
<i>relationship value</i>				
<i>enjoyable to work in</i>	43520	407.3		.000*
<i>proud to bring visitors</i>	43522	1845.5		.000*
<i>customer value</i>				
<i>impact on corporate image</i>	43521	1505.9		.000*
<i>environmental value</i>				
<i>impact environmental sustainability</i>	43524	1139.4		.000*

4. Results

The design of the workspace mattered to most employees (85.2% agreed with this statement), both in ABW and in dedicated seating environments (see Figure 2). But in ABW environments significantly more employees agreed on this (see Table 1). Looking at the use value that was experienced by both groups of employees, on all matters the ABW employees were more

positive than the ones with dedicated seating. The perceived support of important activities by ABW employees was higher ($M=.79$, $SD=1.2$) than among the dedicated seating employees ($M=.59$, $SD=1.2$). Workplace satisfaction in general with the features and with the facilities also showed significant higher scores for the ABW group than the TradWoW employees. ABW employees scored (on a scale from -2 to +2) the features on average with .19 ($SD=.45$) and facilities with .39 ($SD=.49$) and dedicated seating employees with .13 ($SD=.46$) and .24 ($SD=.47$). Looking at the individual features and facilities, satisfaction of ABW employees was higher for all facilities (except desk/room booking systems) and for most of the features (e.g. indoor climate, parking, meeting rooms, accessibility, noise and décor), except for their desk, chair, personal storage, phone equipment, in-office network connectivity and the ability to personalise. The last question on use value regarded the support of productivity and again ABW employees felt better supported by their workspace (see Figure 3 and Table 1).

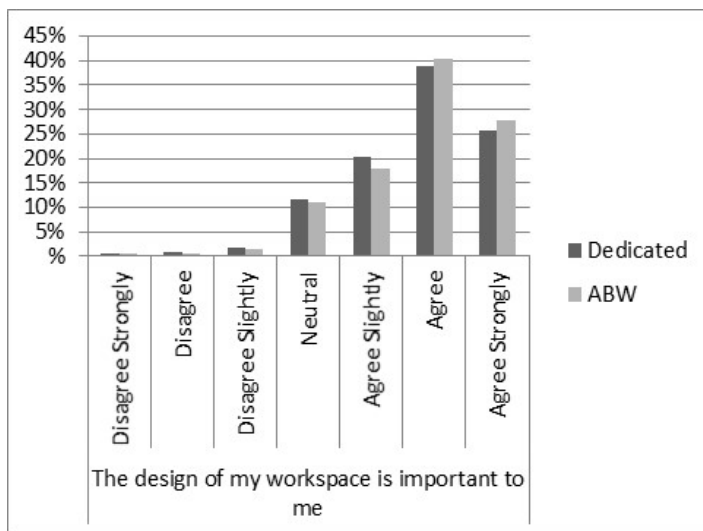


Figure 2: Importance of workspace design

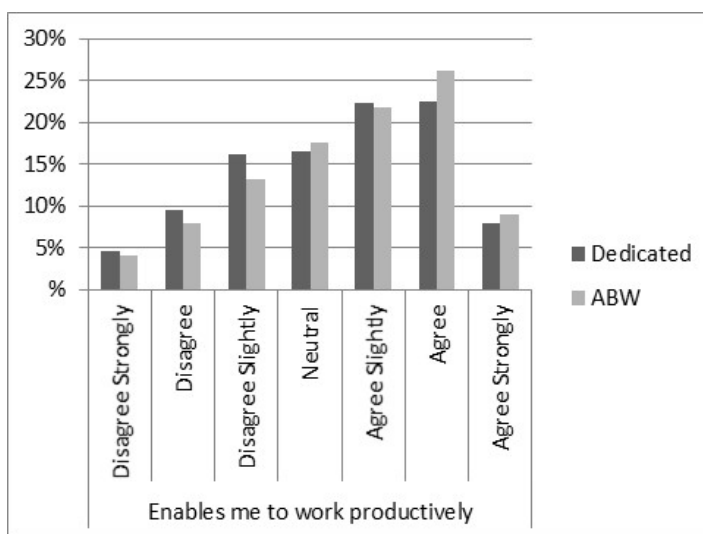


Figure 3: Added use value through support of productivity

Besides use value, the ABW employees also valued the added social value of their workspace. The impact on workplace culture was more positive and also the contribution of the workspace to a sense of community at work (see Figure 4 and Table 1). Both these items are known to help connect people. The last indirect added value through the employees is relationship value, which also scored very highly in the ABW environment. The employees felt more strongly about the fact that it creates an enjoyable environment to work in and they felt more proud to bring visitors to their workplace. Figure 5 shows that especially pride was much higher among the ABW employees.

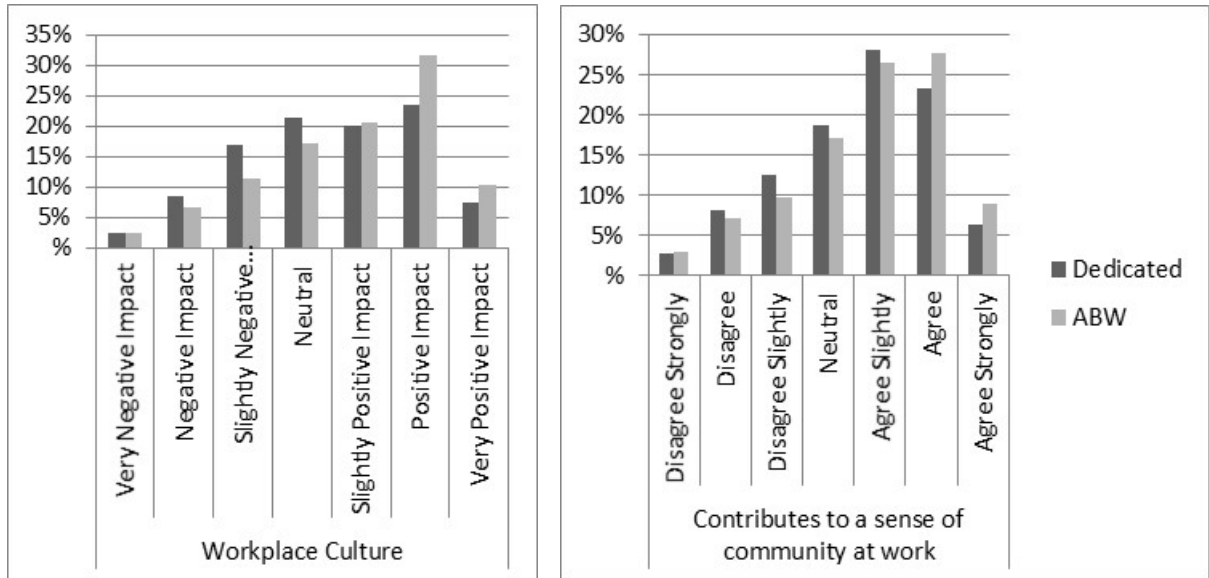


Figure 4: Added social value

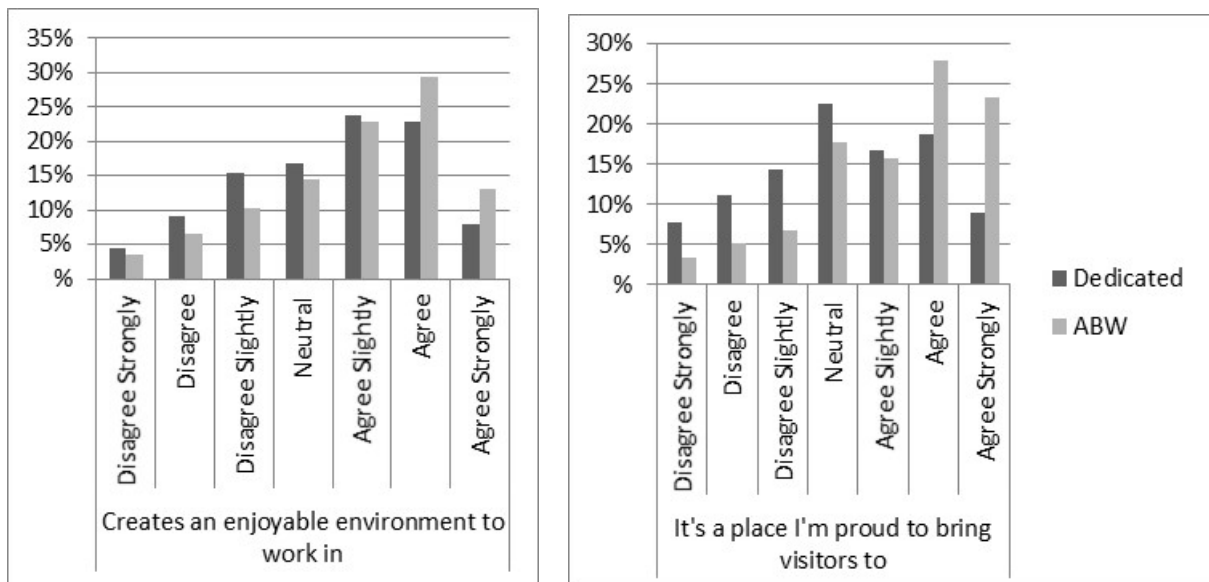


Figure 5: Added relationship value

Although customer value and environmental value are indirect added values which are best measured by opinions outside the organisation, it is also interesting to know what employees have to say about it. With regard to customer value, employees felt more strongly that their ABW environment had a more positive impact on corporate image and environmental sustainability (see Figure 6). Opposed to use, social and relationship value, these ‘outside’ values might be the hardest for CREM to quantify the actual effect for, as it is not common to question customers and society about this. For the question on environmental sustainability 42.2% of the respondents remained neutral, which might also imply that they did not know how to value this aspect.

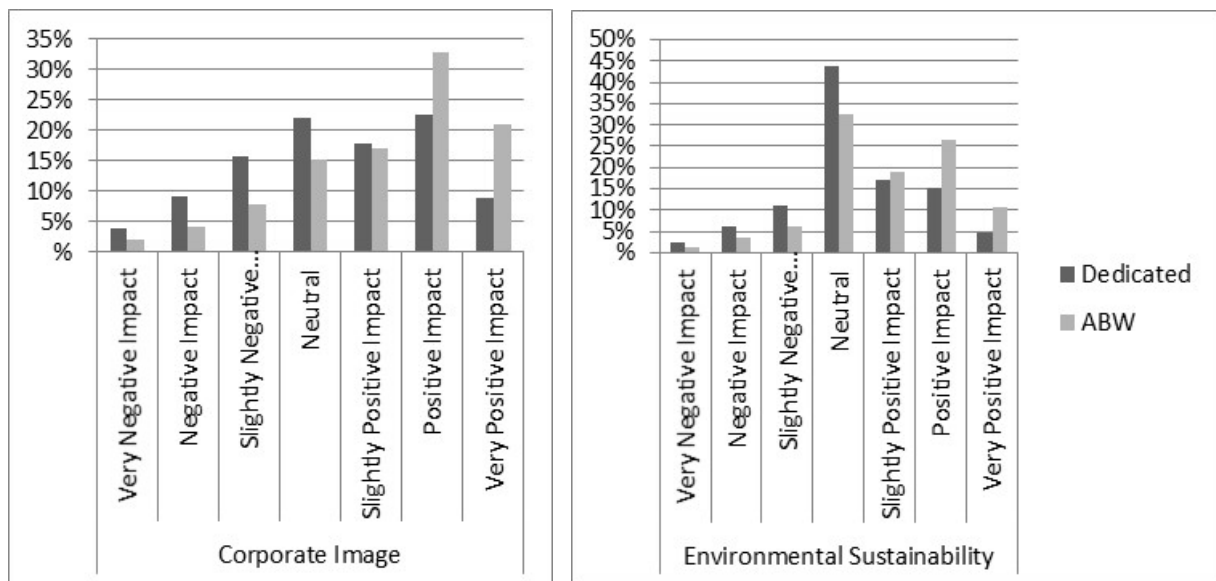


Figure 6: Added customer value and environmental value

5. Discussion

In today’s knowledge economies, the employees are the most important asset. To measure their perception with regard to use value, social value and relationship value probably has provided valid results, as these are perceived values. However, for customer and environmental value it would be better for future research to also include research among clients, passers-by and local residents. In future comparisons of NewWoW and TradWow environments, it is also important to take the building itself into account. It is likely that the ABW environments in general were newer (or more recently renovated), which has probably led to more modern climate installations and decor.

The results of these analysis showed that ABW environments scored better on almost all aspects and added values. That would imply that all organisations can improve their performance by moving from dedicated seating towards these types of work environments and NewWoW. However, ABW might not be suitable for all job types and also not for all types of people. Also, research has shown, that these environments are not always used as intended, because people still claim the same seat everyday anyway and do not change during the day (Appel-

Meulenbroek et al, 2011). If employees are not guided well during the implementation, they might even oppose the intended changes on purpose (Inalhan, 2009).

It is unknown which added value is the most important for organisations and their performance. For knowledge organisations it would seem that social value is particularly valuable as knowledge sharing increases the innovativeness of the organisation. Asking about the contribution of the work environment to workplace culture and a sense of community probably did not cover this entire concept of social value yet. Innovation requires stimulation of both interaction and creativity (Oseland et al, 2011) and CREM can take specific steps to do so with the physical work environment design (Kastelein, 2014; Dul and Ceylan, 2014). These studies have not yet identified whether ABW are better at it than traditional work environments, so this is subject to further research.

Looking at satisfaction with some of the individual features and facilities that scored negative for both groups, it becomes clear that people walking past your desk and noise levels are not solved satisfactory in any of the work environments (as there was no significant difference). And although satisfaction with temperature control and art/photography were significantly less negative among ABW employees, they were still dissatisfied a lot. After desk, chair and different types of office equipment, temperature control was important for the highest percentage of respondents. So research how CREM can add value with these important aspects is necessary, as it does not seem that the modern ABW environments have succeeded (much) in doing so.

6. Conclusions

The physical work environment is very important to office employees, both in contemporary as in more traditional work environments. Therefore CRE management can add value to the organisation by offering important features of the physical work environment and facilities to the satisfaction of their client's employees. The results of this study suggest that on average (European) employees were happier and supported better with ABW environments than with dedicated seating, so introducing these office concepts seems promising for CRE managers to add more value. Besides the exchange value that it will bring (through reduction of m²'s), the respondents felt that also all the other added organisational values benefit from it. The challenge for CREM remains to express all the added values in terms of money, as interventions in the physical environment do require an investment and thus approval of corporate management.

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Measuring the added value of housing for primary education

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Abstract

The purpose of this paper is to investigate which theoretical elements of adding value by real estate are applied in practice in accommodating primary education and in what way these are elements relevant to the stakeholders. A literature study of usual CREM strategies has been used to build a theoretical framework with regard to the value a building can create for different stakeholders. Then interviews were held with various professionally involved people in order to understand to what extent the general theory is taken into account with regard to “added value” for the stakeholders of primary school buildings. The factors marketing, increased satisfaction of employees, increased productivity, flexibility, and reduction of costs were mentioned explicitly as possibilities to add value for stakeholders by real estate. It seems reasonable to assume that the sector of primary education strategically focuses little on increasing the value of real estate. The article summarizes the theory of the added value of real estate for organisations. The empirical findings show that professionals are aware of the possible added value of real estate for the primary process. The added value is expressed in many ways and is also perceived differently by the stakeholders. However, the possibility to add value by real estate hardly ever plays a role in a real estate strategy, nor is it used as an argument to increase available budgets. Due to the limited number of interviews, further research is needed regarding the assumed relationship between real estate strategies and the perception and behaviour of the different stakeholders. In The Netherlands, various studies have been conducted into the importance of CREM theory for decisions on real estate for Higher Education. Similar research on housing for primary education is almost lacking. The data show that not all potential possibilities to add value with real estate for primary education seem to be applied in practice.

Keywords: Corporate real estate, Added Value, Primary education, Stakeholders

1. Introduction

The main purpose of this research is to give insight in the way primary school buildings can add value, from the perspective of different stakeholders. Most of the recent literature (Jensen et. al, 2012 and 2014), (Beckers et. al., 2015) is about the added value of the process of CREM or FM to an organisation. Research with a focus on the meaning of added value for the different stakeholders of a specific school building itself, is lacking for primary education.

In order to get the best out of the real estate of an organisation, it is vital to see real estate not only as a shell within which the organisation's everyday activities and processes take place, but to see it as a capital asset that can be used for goals that may be achieved in the longer term (Appel-Meulenbroek, 2007). Lindholm (2006) concluded that the possibilities of adding value through real estate often were not recognized or even considered. Therefore, it is an obvious assumption that a strategic planning with regard to the real estate of organisations also can influence the results. A lot has been written about what this means for the "for profit sector". More and more, the CREM principles are applied to real estate with a public function.

De Vries (2007), Den Heijer (2011) and Kok (2014) did research on the importance of CREM and FM for decisions on real estate for higher education and universities. Their research showed that housing had a direct influence on the primary process of universities. For instance, the change in the funding of universities has led to a change in the process of prioritising. Previously, cost efficiency, architectural quality and centralization were prioritised, whereas factors like customer appreciation and social cultural aspects are considered more important now (Geselschap, 2013).

For higher education institutions there also is research available about the relationship between Corporate strategies and real estate management. Beckers (2015), for instance, found that the CREM strategies in use, nowadays are more clearly aligned with the corporate goals of an institution. Based on a comprehensive literature review De Kok (2014) found that the assessment of added value of a facility depends on the perceived functional or emotional advantages offered by that facility in relation to the costs, efforts and the risks involved in using that facility. According to Appel-Meulenbroek (2014), it is obvious that more fundings will be made available for investments in real estate if there is proof that real estate adds value to the organisation. Most likely, the CREM principles can also be applied to other sectors in education in The Netherlands, like for instance primary education. Similar research on the effects of real estate management on certain decisions with regard to housing for primary schools has not been done yet.

In the current situation, school boards receive the financial means for exploitation of the school directly from the Ministry of Education. Financial means for building and renovating school buildings are not included, because, in principle, a municipality is legally obliged to place a school building at disposal. For this, the municipalities receive funds from the so called "Municipal Fund". These funds, however, are not "earmarked" for school buildings. Based on the current regulations, one could opt for further decentralisation. This implies that the financial means for the realisation of the school buildings are made available to the school boards and that further agreements with the municipality have to be made about the conditions in which way the means can be spent by the school board. In primary education, this possibility is hardly

made use of. Although there are other possibilities to divide the financial means for school buildings, the question remains whether these possibilities provide sufficient freedom of policy to the school boards in the present situation. It could very well be that, if the means could be spent directly by the school boards, it would be possible to create school buildings that add more value to the organisation.

Real estate is generally recognized as the fifth business resource (Joroff, 1993). Several authors have written about the “added value of Real Estate”. Nourse and Roulac (1993) and Krumm et. al. (1998), among others, wrote about the added value of real estate for an organisation. Later, Lindholm et. al. (2006) and Jensen (2010) wrote about a “framework that describes how real estate and facility management can create added value, either in a corporate real estate context or in a facility service provider context”.

In the current situation the complicating factor is that the municipality, as a result of current regulations, often is the beneficial owner of the building, and the school board just the legal owner. In this situation, the question arises whether the real estate should be seen as the fifth business resource to the school board or the municipality. The role of the real estate as a business resource for the municipality is very different from the role it has for the school board. Because municipalities are the beneficial owners of the school buildings, they will probably steer towards financial performance indicators (cost minimization), whereas a school board is likely to be more interested in the added value that the building can give because of the role it plays in the educational process.

This article aims to answer the following questions:

1. What is, in general, perceived as “the added value of real estate”;
2. Who can be regarded as the stakeholders of housing of primary education in The Netherlands;
3. To what extent are the theoretical possibilities of adding value with real estate recognisable in relation to the stakeholders of the school buildings for primary education.

Below the methodology that has been applied when answering these questions will be described. Subsequently, the results will be summed up, followed by the conclusions.

2. Method

The first two questions are necessary in order to describe a solid theoretical framework. The answers to these are based on a literature study. This research has provided a theoretical insight with regard to the possibilities for creating “added value” and the stakeholders that can be distinguished when it comes to housing of primary education. This resulted in a hypothesis regarding the relationship between the stakeholders and the possibilities to add value with real estate. Subsequently, this hypothesis was tested through interviews.

These interviews were held with representatives from several groups of stakeholders, in order to find out to which extent the principles from theory actually “live” in practice. These interviews were held with four school board members, four actors with an advisory role, and a

representative from a municipality. A representative of one of the largest school boards in The Netherlands, a board member and an advisor of one of the most progressive school boards in The Netherlands, a member of a board of public education that has been involved in a lot of new housing projects during the past years, and finally a representative of a municipality, a representative of a school board and an advisor that are currently working on a number of innovative school buildings have been interviewed. The question has also been answered by a legal expert in the field of housing of education and to a housing advisor who has been involved in several school construction projects.

The interviews were held according to the narrative method. The only question asked was: “from your perspective, which added value could housing of primary education have for the various stakeholders (municipality, school board, employees, parents and children, and the environment)?”. The purpose of this approach was to find out to what extent the theoretical possibilities of adding value to an organisation by means of real estate, for the benefit of the stakeholders, was recognised by the interviewed professionals. The interviewer has asked as little extra questions as possible. The interviews were recorded with the consent of all interviewees and were transcribed completely afterwards.

3. Current Theory

Here the result of the literature study will be described. Firstly, the functions that real estate can fulfil will be taken up and the existing theory with regard to the value of real estate for an organisation will be described. Subsequently, the different stakeholders of real estate and which types of added value theoretically are applicable to each of them will be taken up.

3.1 Functions of Real Estate

Each individual real estate object has multiple functions. In his thesis “Focus on customer value”, Smeets (2010) mentions five functions of real estate at object level. These five functions are listed below.

- the protecting function: Real estate fulfils the human need of conditioned space by providing both the necessary biological/physiological and physical shelter and mental shelter in the social and psychological sense. In short: we need a roof over our heads that protects us against weather conditions and that gives us privacy.
- the utilitarian function: Accommodation and organisation of necessary human activities and utterances, both personally, socially, culturally, educationally, sportily, economically, etc. Concretely, real estate offers a place to work, to learn, to train, etc.
- the domain and spatial function: The relationship of real estate with the environment in all its different levels makes it the starting and ending point of a social and economical network, in other words a meeting point in terms of accessibility, as well as a starting

point for economical and social relations and activities. At the same time, it offers the option to withdraw from these.

- the communication and symbol/status function: Real estate is a medium to disseminate the (intended) own identity and the distinguishing status of the acquired social and economical position. It gives the possibility to realise a certain desired look by, for instance architecture.
- the financial/economical function: The capital intensive character, both in terms of investment needed and maintenance, implies a relation between the financial and fiscal equity position and its development. Thus, an owner who lets a property has a source of income. A user considers the costs of property as necessary within the production process.

The same functions are described in a slightly different wording by De Vries (2008). She gives a broader interpretation to the communication and symbol/status function, and includes the domain and spatial function in this category. According to De Vries, this results in only four functions. Since for real estate for education in particular the domain/spatial function is very clear, Smeets' principle will be followed.

Because it fulfils the above mentioned functions, real estate is often regarded as the fifth business resource of an organisation (Joroff et. al. 1993). Just like capital, know-how, technology, and human resources, real estate can add value by contributing to the realisation of an organisation's goals (Den Heijer, 2011). Previous literature, as summarised by De Vries et. al. (2008) shows that there are in fact two ways to improve an organisation's achievements. On the one hand by increasing the turnover, on the other hand by reducing the costs. Liow and Choulet (2008) call this the "Business perspective of CRE", with the following indicators: "costs", "profitability", and "productivity". In addition they mention "the financial perspective of CRE", which means that owning real estate influences a "firm's credit facility, its financial statements, and its operating economics.

According to Appel-Meulenbroek (2007), real estate has a direct influence on the achievements of an organisation, for instance through lower maintenance costs and reduced energy consumption, but mainly through the indirect effects that the real estate has on employees, visitors, and processes. Therefore, real estate has an important role in the process of creating value by an organisation.

In the past, several authors have defined the various interventions with regard to real estate that can influence an organisation's achievements. Veuger (2014) states that "by Corporate Real Estate Management (CREM) the real estate portfolio can be brought into line with the requirements of the core business of the corporation". His research, based on a comprehensive literature study, resulted in a number of lessons learnt from Corporate Real Estate Management. These lessons are listed in the figure below.

<i>13 Lessons</i>	
1	Real estate can contribute to improving an organisation's social objectives.
2	A company-specific approach to creating value from real estate management makes a greater contribution to the company's objective.
3	Making the added value measurable is essential for the role as a real estate discussion partner in a company in which strategic decisions are made.
4	Becoming more flexible in the static nature of real estate and the speed at which society develops can be addressed by consciously thinking about the longer term. Decisions need to be taken in this regard that create opportunities for future optimisation.
5	Real estate interventions and effects reinforce the organisation's objective.
6	One of CREM's jobs is to formulate and implement an optimum solution.
7	CREM is playing an important role in reducing the burden of debt and building a dominant market position.
8	Sustainable competitive advantage compared to other companies is determined by three generic strategies that do not always go together: focus, differentiation and low cost.
9	Effects follow different eventualities and depend on the organisation's starting position and culture.
10	Cause-effect chains are unclear due to influences by several factors and performances are formed by complex end-means chains.
11	Real estate interventions depend on starting position and policy choices, in which context is subject to change.
12	A target-focussed company provides more consistent reasons for real estate interventions.
13	Collaboration is necessary in order to achieve social results, in which one monopolistic arrangement cannot deliver the benefit of values. Politics also has its own dynamics and interests that can cause rational considerations to disappear into thin air.

Figure 1: Lessons learnt from Corporate Real Estate Management (Veuger 2014: 132).

This has been elaborated concretely by Lindholm et. al. (2006). It appears from the above that different interventions can influence all kinds of achievements of real estate. Real estate can be of added value for an organisation through (1) increased value of property, (2) marketing, (3) increased innovations, (4) increased satisfaction of employees, (5) increased productivity, (6) increased flexibility, and (7) reduction of costs.

After this the question who can be regarded as stakeholders of housing of primary education will be answered. Subsequently, these stakeholders will be linked to the different ways in which real estate can add value to an organisation. It is important to understand this in order to be able to weigh the interests of the stakeholders when making a decision with regard to the real estate.

3.2 Stakeholders

When deploying a building, various stakeholders can be distinguished (among others Den Heijer, 2011, De Vries, 2007, and Mobach, 2009). Generally, this mainly concerns the owners, the users, and the environment of the real estate.

From the perspective of the Corporate Real Estate Management (CREM), Den Heijer (2011) distinguishes the stakeholders according to different functional domains: Strategic (Policy makers), Financial (Controllers), Functional (Users), and Physical (Technical managers).

Kemperman et. al. (2013) describe creation of value as “the sustainable result for all parties” and they distinguish value for customers, value for employees, and financial value. Stakeholders of companies are individuals, groups of individuals, or organisations that are influenced by how the companies function (Van den Bosch, 1996).

Lindholm (2006) notes that an important part of the effects of CREM in practice is measured with instruments that are based on the Balanced Score Card (BSC) system, which was developed by Robert Kaplan and David Norton in 1992. Within the BSC system, four focus areas are distinguished: the financial, the managerial, the innovating, and the customer perspective. When these four perspectives are linked to the stakeholders that have been defined with respect to housing of education, it appears that the stakeholders sometimes have to do with several perspectives.

Converting this to school buildings, it seems that municipalities and school boards have interests in their role as owners, and that employees and parents and children have interest from their role as users. It is not unlikely that these stakeholder interests could overlap partly. For instance, a school board does not only have interests as an owner, but as a user as well.

It is more difficult to interpret the environment as a stakeholder of a school building. When thinking of a specific building, one could think of the immediate neighbours. On a more abstract level, one can even consider society in general, because of the significance of primary education. However, confining ourselves to the aspects that are manageable for decision makers with regard to a specific building, it concerns the immediate neighbours and the nearby area.

The above mentioned has provided a theoretical framework according to which the interests of the stakeholders of housing of primary education can be related to all possible real estate strategies. The table below shows the relation between the stakeholders and the previously mentioned strategies to add value to an organisation through real estate. The figure shows that, for most stakeholders, real estate can add value in many different ways. The figure shows the assumed relevance of the way in which real estate can add value for the different stakeholders. This assumption has been tested by means of a number of interviews with school boards, municipalities, and advisors.

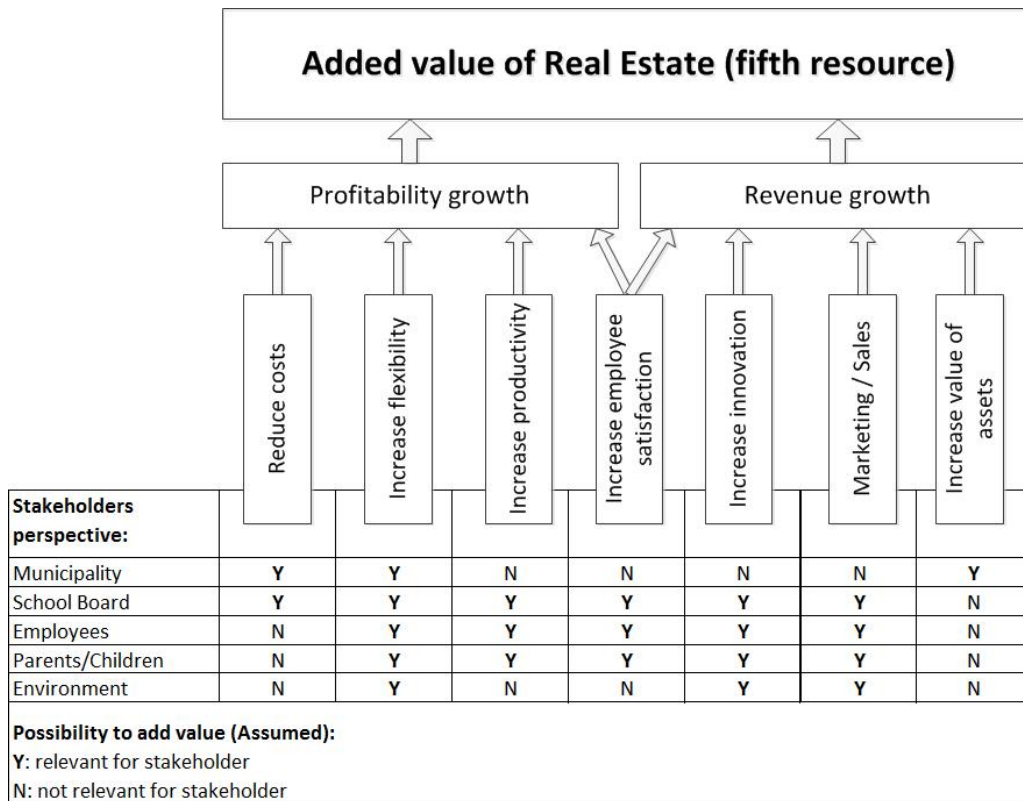


Figure 2: own adaptation D. Kootstra 2015, based on Lindholm et. al., 2006

4. Empirical findings

Finally, the results based on the interviews will be given. As mentioned before, the interviews were held according to the narrative method. The only question asked was: “which type of added value should housing of primary education, seen from your perspective, have for these stakeholders: municipality, school board, employees, parents and children together, and the environment?” The different stakeholders were mentioned in the question, but not the different ways in which the building could add value for them.

This way was chosen in order to get an idea of the awareness of the different parties with regard to the possibilities of adding value to the organisation through the property. For that reason the results will be listed per strategy and not per stakeholder.

(1) Increased value of the property: Contrary to what was expected, this possibility to add value to an organisation was not mentioned in any of the interviews. Assumed was that added value could at least be found in limiting the depreciation of buildings. Considering the situation with regard to funding of housing of primary education in The Netherlands, where the municipality is the beneficial owner of the school buildings, it was expected that this possibility of adding value would be relevant for the municipalities at least.

(2) Marketing: This function of real estate is clearly recognisable in the sector of primary education. The interviews confirm clearly that a new, or at least a good-looking building “sells” to parents who are looking for a school for their child. Marketing is used in different ways though. Some school boards choose to use the building as an instrument to increase their market share. Other school boards have, from this very understanding, made agreements to divide the children over the different school buildings as well as possible, in order to get to an efficient capacity utilisation of the buildings.

The Marketing function is related to the environment as well. As said, in this research “environment” is explained as the immediate neighbours and the nearby area. In particular the municipality seems to be designated to look after the interests of the environment as a stakeholder. This is because of the steering tools a municipality has available for spatial planning. Seen from this role, the municipality can influence the location and the appearance of a school building.

Sometimes schools are placed in an accommodation where cooperation with for instance a community centre or an organisation organising activities for children is brought about. Also, a few examples were mentioned where the municipality stimulated sustainability investments. However, this was not done for financial reasons, but proceeding from a sustainability ambition.

(3) Increased innovations: Of course, the school as a “not for profit” organisation is not aiming for market innovations. The primary process is focused on childrens’ learning and not on innovations. It turned out from the interviews that the stakeholders do apply innovative concepts in order to achieve education that suits modern times. With this in mind, the building teams are made up multidisciplinary. They are also advised professionally, to make sure that a new building does not just become a modernised version of an old building. Innovation as a way to increase revenues is obviously not an issue for primary schools. The benefits of an innovative building concept will mainly be reflected in the increased user satisfaction, increased productivity, increased flexibility and cost reduction, as mentioned below.

(4) Increased satisfaction of employees: The role that a building plays in the work perception of employees was recognised in most cases. As the employer, the school board is responsible for this aspect. None of the interviews have given reason to believe that savings in the form of less sick leave were associated with a higher budget for a school building though.

(5) Increased productivity: The interviews left no doubt about the role that is seen for a good building in primary education. Good housing is a condition for education. A building has to support an educational concept and through a good climate make it possible for children to keep learning and for teachers to keep teaching.

(6) Increased flexibility: This aspect is of importance at different levels. On the one hand, flexibility with regard to the needed capacity is a factor. One has to consider which capacity is needed in which phase of the “life” of the building. On the other hand, flexibility with regard to the possibility of using the building differently within education is important, so that one can move along with the changing methods of education.

(7) Reduction of costs: The interviewed professionals linked the financial aspects of housing for education to the school boards. As mentioned before, this does not concern the possibilities for

increased value of the properties, but the exploitation costs. Now that school boards since 1 January 2015 can dispose of the financial means for external maintenance of the building themselves, this aspect on the border of renovation and construction leads to discussions between municipalities and school boards more often. After all, municipalities are responsible for the expenses of construction, whereas school boards pay for renovation.

The interviews have given a clear indication that real estate, in accordance with the theoretical possibilities, is used as a means to reduce costs in the form of exploitation expenses, such as costs for energy, maintenance, and cleaning.

5. Discussion

Though the number of interviews was limited, the results still give reason to further investigate the assumed relation between real estate strategy and stakeholders. This research has made clear that the seven usual real estate strategies (in other words, ways to add value to an organisation) can very well be linked to the interests of the stakeholders of a school building. Only the strategy of adding value by increasing innovations does not seem to fit for the housing of primary education.

The interviews also made clear that “Environment” as a stakeholder could very well mean more than just the immediate neighbours, as was assumed. For instance, also the institutions that benefit from the use of school buildings after school time and children using the playground after school, could very well be seen as a different category of users.

6. Conclusions

On the basis of this research, the conclusion seems to be justified that a school building should be seen as the fifth business resource for school boards, but not for municipalities. The interviews confirm that the people involved seem to be aware of the meaning (or the added value) of real estate for the primary process. The different parties express this in very different ways.

The research has not provided any evidence that these aspects are used to apply the available funds for housing for education differently. Most remarkable is that none of those interviewed sees possibilities in the value development of the property, for instance by restricting depreciations.

The interviews also show that this possibility to create value hardly ever plays a role in a real estate strategy, or is used as an argument to increase available budgets. No indications have been found that school boards make use of a clearly defined strategy in which the investigated possibilities for adding value are used. Possibly, the parties concerned are insufficiently aware of these possibilities.

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Bus Transportation Accessibility – Does It Impact Housing Values?

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Abstract

Integrating public transportation and land use policies is one of the key strategies in an attempt to achieve more sustainable communities. While economic consequences are an essential dimension in decision making, there is yet very limited evidence for the impact of accessibility to bus transportation on surrounding residential property values. This study is the first of its kind investigating the price impact in Tampere – the largest city outside the capital region of Finland. An empirical strategy utilizing fixed-effect hedonic pricing models has been applied to specify valuation effects of accessibility to bus transportation.

A premium of 1.1 percent was estimated for housing units located no farther than 50 meters from a bus stop. Housing units located in zones with more diverse amenities and better bus connections were also estimated to be higher appreciated, with the exception that housing units in Private car zone sell at higher prices than units in Intensive public transportation zone. As Tampere is a relatively monocentric city with great coverage and service frequency of public bus transportation, the distance to CBD seems to be a more important determinant in terms of accessibility than proximity to the closest bus stop; one kilometer increase in distance to CBD was estimated to command 4 percent depreciation in housing values.

As there are significant differences between cities, some limiting factors should be taken into account when interpreting the results. Price impact on residential property values was studied only in Tampere, Finland, and it is important to notice that the city structure, extensive coverage of the bus network, local market conditions, and other potential differences between cities may have a notable impact on the outcomes. Thus, more studies are needed before the results may be generalized across other geographical locations.

The evidence gained in this study can be utilized when striving for more viable and sustainable cities. Understanding the influence of accessibility to bus transportation on housing values should be of interest to a wide range of city planners, policymakers, and community stakeholders.

Keywords: bus stops, bus traffic, housing prices, public transportation, residential property values, traffic related zones, urban form

1. Introduction

Integrating public transportation and land use policies has been identified as one of the key strategies in an attempt to achieve more sustainable communities (Newman and Kenworthy, 1996; Todes, 2012). It has also been recognized that public transportation investments and land use policies may induce changes in housing prices. (Du and Mulley, 2006; H.M. So et al., 1997; Henneberry, 1998).

Accessibility of public transportation is one of the factors taken into account when city planners are searching for to identify potential locations for new housing. In addition to their influence on land use decisions, public transportation stops may also impose externalities capitalizing into housing prices (Cervero and Kang, 2011). Previous studies have found that investments in public transportation may – particularly within walking distance – command a premium in housing prices (Dubé et al., 2013). However, Mohammad et al. (2013) suggest that due to researchers' tendency to publish only statistically significant results, published literature may introduce a biased general view of housing price effects from bus transportation.

Property value effects may depend on income level of residents in the area (Munoz-Raskin, 2010). Osland and Thorsen (2008) argue that there are two important components of accessibility that should be taken into consideration when estimating housing price effects. The first component is accessibility to central business district (CBD) where urban attractions are located, and most of activities occur. The second major component is recognized to be labor-market accessibility as commuting to work places is a central part of people's daily lives.

Public transportation connections are usually relatively stable, which may promote their propensity for capitalizing into housing values. However, the propensity may be dependent on transportation technology. A subway or suburban train is usually associated with higher appreciation in housing prices than bus connections (Bocarejo et al., 2013). The reasoning behind this may be that rail traffic always requires heavy infrastructure and substantial investments, resulting in relatively permanent structures. While, it is much harder to predict future development of bus connections as substantial investments on infrastructure are not needed, and thus, the system is more flexible for changes. Consequently, the impact of bus connections on housing prices may be less than what alternative forms of public transportation would induce.

Given that both positive and negative estimates of land and property values have been reported in different studies investigating rail project impacts (Mohammad et al., 2013), it is not self-evident that the impact from public transportation would only be positive. Although improvements in accessibility are likely to induce positive impacts, also a number of negative externalities, such as increase in noise and crime, can be linked to a better access to public transportation (Pope and Pope, 2012; Szczepańska et al., 2015). Attempts to control traffic volume by road tolls has been reported to have minor positive impact at least on residential leases which may result from decrease in negative externalities (D'Arcangelo and Percoco, 2015).

To date, there are relatively few studies investigating the impact of public transportation on housing values in developed countries. Mulley (2014) argues that, presently, there is a lack of evidence for the residential land value impact of bus networks in the developed countries. Particularly, the housing price impact from bus transportation in the Nordic Countries is underexplored. This study contributes to the existing body of literature, addressing the void in knowledge by investigating the impact of accessibility to bus transportation on housing prices in Tampere, Finland.

2. Data and Public Transportation System in Tampere

The data utilized in this study is from the city of Tampere in Finland – the largest urbanized area outside the capital region and home to more than 220,000 residents by the end of December 2015. Tampere is also the provincial center of Pirkanmaa region with slightly more than 500,000 residents. Tampere is an example of a quite monocentric city as for its bus network. Interestingly, the city center can be accessed through almost every bus line with only a couple of exceptions that do not pass through the city center. The public transportation system is mainly based on busses as there are no subways or streetcars. Tampere railway station is one of the central hubs in the Finnish railway network. However, the only stop for passenger trains is the Tampere central railway station located in the city center. Thus, in Tampere, the railway network only serves transportation to other cities and municipalities, but not the local traffic within the city limits. As the public transportation is relying on busses, Tampere is a potential geographical location to be studied to reveal the relevance of bus network to housing prices.

The impact of accessibility to bus transportation on residential property values was investigated by utilizing five unique datasets, including i) housing sales transactions from 2008 to 2012, ii) complete property registry for the city of Tampere, iii) spatial boundaries for traffic related zones of urban form (©SYKE), iv) locations of bus stops in the city of Tampere, and v) grid data containing information on residents' median income (©SYKE and TK). The spatial nature of the data allowed all five data sets to be combined using locational attributes.

The Finnish housing market is diverse in nature with property types ranging from single-family detached to multifamily apartment blocks. The average housing unit was constructed 39.8 years ago and sold for €137,047 (or €2,179 per square meter for a 62.9 square meter unit). The average number of rooms was 2.4 including bedrooms, living rooms, and studies, but not kitchens, bathrooms, private saunas, and walk-in closets. Private saunas are an important amenity, associated with 45 percent of the apartments sold. Housing transactions occurred on average in areas where the annual median income is 32,997 € and distance to Tampere Central Square is 4.42 kilometers. 63 percent of sold apartments were considered to be in good condition, whereas brokers reported 22 percent to be in acceptable condition and 1 percent in poor condition. Condition for 14 percent of the observations was not reported. 2 percent of the sold apartments were located in properties that have an elevator. The average distance to a bus stop was 137 meters. 22 percent of the transactions were located in Pedestrian friendly zone, 1 percent in Fringe zone, 19 percent in Public transportation zone, 9 percent in Private car zone, and 5 percent in Suburban center zone. The remainder of 44 percent was located in Intensive

public transportation zone, which was the comparison level for the analysis. Table 1 presents summary statistics for the residential transactions.

Table 1: Summary statistics

<i>Variable</i>	<i>Mean</i>	<i>Std dev</i>	<i>Min</i>	<i>Max</i>
Sale price (€)	137,047	63,451	40,000	750,000
Property age (years)	39.8	20.1	5	160
Unit size (sq. meters)	62.9	23.9	15	275
Weeks on market	38.1	25.7	1.0	104.0
Number of rooms	2.4	1.0	1.0	8.0
Maintenance dues (€)	163	67	0.0	867.0
Floor number	2.6	1.8	1.00	12.00
I{Multi-story apartment block}	0.79	0.41	0	1
I{Townhouse}	0.17	0.38	0	1
I{Single-family house}	0.02	0.14	0	1
I{Duplex}	0.02	0.14	0	1
I{Sauna}	0.45	0.50	0	1
I{Elevator}	0.02	0.16	0	1
Income	32,997	13,234	9305	105796
Distance to CBD (km)	4.42	2.77	0.06	10.81
I{Condition: Acceptable}	0.22	0.41	0	1
I{Condition: Poor}	0.01	0.12	0	1
I{Condition: Unavailable}	0.14	0.35	0	1
I{Pedestrian zone}	0.22	0.41	0	1
I{Fringe zone}	0.01	0.12	0	1
I{Public transport zone}	0.19	0.39	0	1
I{Private car zone}	0.09	0.29	0	1
I{Suburban center zone}	0.05	0.22	0	1
I{Not within a zone}	0.12	0.32	0	1
Distance to bus stop (m)	137.49	86.56	7	756
I{Bus stop within 50 meters}	0.11	0.31	0	1
I{Bus stop within 100 meters}	0.38	0.49	0	1
I{Bus stop within 150 meters}	0.65	0.48	0	1
I{Bus stop within 300 meters}	0.95	0.21	0	1

Notes: This table presents the means, standard deviations, minimum and maximum values for the full sample of residential transactions. Price is the transaction price for residential units, in Euros (€). Time on market is measured in weeks. Building size and Unit size are measured in square meters. Property age is in years. Floor number is for the unit. The I{·} operator designates an indicator variable, taking on a value of one for the characteristic in brackets and zero otherwise. Property types included in the analysis are Duplex, Single-family (detached), Townhouse, and Multifamily (suppressed). Property condition categories include Acceptable, Poor, Unavailable and Good (suppressed). Maintenance dues are reported as monthly fees in Euros, and take on a value of zero for units in buildings that have no maintenance dues.

3. Estimating housing price impact

The empirical strategy in this study was to estimate a hedonic regression model for residential transaction prices. The objective was to evaluate price differences between different traffic related zones of urban form, and isolate the impact that proximate bus stop has on surrounding housing values while controlling for differences in property characteristics. The first estimated hedonic equation takes the following form:

$$\begin{aligned} \ln(\text{Price}) = & \beta_0 + \beta_1 \cdot \ln(\text{Property age}) + \beta_2 \cdot \ln(\text{Unit size}) + \beta_3 \cdot \ln(\text{Time on market}) \\ & + \beta_4 \cdot \ln(\text{Number of rooms}) + \beta_5 \cdot \ln(\text{Maintenance dues}) + \beta_6 \cdot \text{Floor number} \\ & + \beta_7 \cdot I\{\text{Type: Single family}\} + \beta_8 \cdot I\{\text{Type: Townhouse}\} + \beta_9 \cdot I\{\text{Type: Duplex}\} \\ & + \beta_{10} \cdot I\{\text{Sauna}\} + \beta_{11} \cdot I\{\text{Elevator}\} + \beta_{12} \cdot \ln(\text{Income}) + \beta_{13} \cdot I\{\text{Condition: Acceptable}\} \\ & + \beta_{14} \cdot I\{\text{Condition: Poor}\} + \beta_{15} \cdot I\{\text{Condition: Unavailable}\} + \beta_{16} \cdot \text{Distance to CBD} \\ & + \beta_{17} \cdot I\{\text{Pedestrian zone}\} + \beta_{18} \cdot I\{\text{Fringe zone}\} + \beta_{19} \cdot I\{\text{Public transportation zone}\} \\ & + \beta_{20} \cdot I\{\text{Private car zone}\} + \beta_{21} \cdot I\{\text{Suburban center zone}\} + \beta_{22} \cdot I\{\text{Not in the zone}\} \\ & + \beta_{23} \cdot I\{\text{Distance to bus stop}\} + \sum_{i=1}^4 \beta_{i+23} \cdot I\{\text{Year}_i\} + \sum_{j=1}^{31} \beta_{j+27} \cdot I\{\text{Submarket}_j\} + \varepsilon. \quad (1) \end{aligned}$$

The dependent variable is *Price*, logged. *Property age* is included to reflect the impacts of depreciation and technical obsolescence on housing values. Variables measuring the physical property dimensions include *Unit size*, *Number of rooms*, and *Floor number*. *Time on market* reflects one dimension of real estate marketing outcomes, and *Maintenance dues* reports monthly financial obligations connected to the property sale. *Distance to CBD* captures locational impacts, measuring distance to the Tampere Central Square. Indicator variables are used to classify property pricing according to property type, sauna, elevator and property condition. The sample of property sales spans from 2008 to 2012, and 4 year indicator variables are included to control for calendar year fixed effects. In addition, 31 submarket indicator variables are included to control for geographic differences in pricing at the zip code level. β are parameters to be estimated and ε is the normally distributed error term.

To capture the impact of different traffic related zones of urban form¹ on residential property values, five indicator variables are included for housing units that are located in *Pedestrian zone*, *Fringe zone*, *Public transportation zone*, *Private car zone*, or *Suburban center zone*. Indicator for *Intensive public transportation zone* is suppressed from the equation to refrain from linear combination. Variable $I\{\text{Not within a zone}\}$ is included to capture pricing difference for housing transactions that are not located within any of the above mentioned zones. The log-linear model structure allows the coefficients for included traffic related zone indicators to be interpreted as the percentage difference in housing values to residential transactions occurred in

¹ The classification of traffic related zones of urban form is based on a spatial dataset by the Finnish Environment Institute (SYKE). For a detailed description, please see the Meta Data Portal: <http://metatieto.ymparisto.fi:8080/geoportal/catalog/search/resource/details.page?uuid={96F338EA-75AF-432C-A780-31A3CDECBDF2}> (in Finnish).

the *Intensive public transportation zone*. Furthermore, *Distance to bus stop* variable is included to isolate the impact of proximity to a bus stop. Results from the estimation of Equation (1) are presented in Table 2.

Table 2: Estimated price impact

<i>Variable</i>	<i>Coefficient</i>	<i>(t-stat)</i>
Intercept	8.831 ***	(150.9)
ln(Property age)	-0.144 ***	(-51.5)
ln(Unit size)	0.669 ***	(79.6)
ln(Weeks on market)	-0.013 ***	(-8.7)
ln(Number of rooms)	0.051 ***	(7.7)
ln(Maintenance dues)	-0.012 ***	(-5.1)
Floor number	0.010 ***	(12.9)
I{Townhouse}	0.177 ***	(38.3)
I{Single-family house}	0.266 ***	(18.3)
I{Duplex}	0.232 ***	(25.2)
I{Sauna}	0.131 ***	(36.6)
I{Elevator}	-0.001	(-0.1)
ln(Income)	0.065 ***	(13.6)
I{Condition: Acceptable}	-0.109 ***	(-36.7)
I{Condition: Poor}	-0.207 ***	(-21.3)
I{Condition: Unavailable}	-0.044 ***	(-12.3)
Distance to CBD	-0.040 ***	(-17.6)
I{Pedestrian zone}	0.125 ***	(12.0)
I{Fringe zone}	0.093 ***	(6.4)
I{Public transportation zone}	-0.023 ***	(-6.4)
I{Private car zone}	0.021 ***	(3.9)
I{Suburban center zone}	0.027 ***	(4.2)
I{Not within a zone}	-0.004	(-0.5)
Distance to bus stop	0.000	(-0.0)
Year indicators:	Included (4 variables)	
Sub-market indicators:	Included (31 variables)	
<i>Adjusted R²</i> :	90.97%	
Observations:	12,449	

Notes: This table presents results from the least squares estimation of Equation (1). The dependent variable is Price, logged. The coefficients for I{Pedestrian zone}, I{Fringe zone}, I{Public transportation zone}, I{Private car zone}, and I{Suburban center zone} indicate the estimated price impact of traffic related zones of urban form. The coefficient for *Distance to bus stop* variable indicates the estimated price impact of distance to the closest bus stop. T-statistics corresponding to the coefficients are reported in parentheses. ***, ** and * designate statistical significance for the estimated coefficients at the 1%, 5% and 10% levels, respectively.

The estimated coefficients reveal that housing values are decreasing as properties age, likely resulting from depreciation and technical obsolescence. Housing values are increasing in unit

size, but units that require longer marketing periods are revealed to sell at a significantly lower price. Units with higher maintenance dues are discounted. Units on higher numbered floors sell at a premium, estimated at 1 percent per floor. Single-family, duplexes, and townhouses all sell at positive and significant premiums relative to multifamily apartments (which is suppressed to avoid perfect multicollinearity). In Finland, the sauna is considered a precious amenity, associated with premiums in the magnitude of 13 percent. Elevator does not command a positive premium, which might not be the case if only transactions in multi-story apartment buildings were investigated. Higher median income is associated with higher housing values as wealthier people tend to live in higher appreciated neighborhoods. Housing units located farther from CBD (Tampere Central Square) sell at lower prices, so that 1 kilometer increase in distance commands 4 percent depreciation. Property condition identified as less than good (which is omitted to avoid linear combination) are discounted accordingly.

Estimates of indicator variables for traffic related zones of urban form reveal that housing prices are relatively highest in the Pedestrian zone, which usually indicates location in downtown area, and is associated with 12.5 percent premium relative to Intensive public transportation zone. In Fringe zone premium is estimated to be 9.3 percent, in Suburban center zone 2.7 percent, and in Private car zone 2.1 percent relative to Intensive public transportation zone. While, housing units located in Public transportation zone with weaker public transportation connections than in Intensive public transportation zone sell at 2.3 percent lower prices.

The coefficient for *Distance to bus stop* does not differ from zero, indicating that proximity to bus stop does not have an impact on housing values. However, the price impact is not likely to be linear resulting in that the continuous variable may not tell the whole truth. To further investigate the price impact of proximity to a bus stop another specification of the model was estimated. The second specification of the model takes the following form:

$$\begin{aligned}
 \ln(\text{Price}) = & \beta_0 + \beta_1 \cdot \ln(\text{Property age}) + \beta_2 \cdot \ln(\text{Unit size}) + \beta_3 \cdot \ln(\text{Time on market}) \\
 & + \beta_4 \cdot \ln(\text{Number of rooms}) + \beta_5 \cdot \ln(\text{Maintenance dues}) + \beta_6 \cdot \text{Floor number} \\
 & + \beta_7 \cdot I\{\text{Type: Single family}\} + \beta_8 \cdot I\{\text{Type: Townhouse}\} + \beta_9 \cdot I\{\text{Type: Duplex}\} \\
 & + \beta_{10} \cdot I\{\text{Sauna}\} + \beta_{11} \cdot I\{\text{Elevator}\} + \beta_{12} \cdot \ln(\text{Income}) + \beta_{13} \cdot I\{\text{Condition: Acceptable}\} \\
 & + \beta_{14} \cdot I\{\text{Condition: Poor}\} + \beta_{15} \cdot I\{\text{Condition: Unavailable}\} + \beta_{16} \cdot \text{Distance to CBD} \\
 & + \beta_{17} \cdot I\{\text{Pedestrian zone}\} + \beta_{18} \cdot I\{\text{Fringe zone}\} + \beta_{19} \cdot I\{\text{Public transportation zone}\} \\
 & + \beta_{20} \cdot I\{\text{Private car zone}\} + \beta_{21} \cdot I\{\text{Suburban center zone}\} + \beta_{22} \cdot I\{\text{Not in the zone}\} \\
 & + \beta_{23} \cdot I\{\text{Bus stop close}\} + \sum_{i=1}^4 \beta_{i+23} \cdot I\{\text{Year}_i\} + \sum_{j=1}^{31} \beta_{j+27} \cdot I\{\text{Submarket}_j\} + \varepsilon. \quad (2)
 \end{aligned}$$

The second specification is consistent with Equation (1) with the difference that the continuous variable *Distance to bus stop* is replaced with an indicator variable $I\{\text{Bus stop close}\}$. To understand the price impact of proximity to a bus stop, four separate variations of the model were estimated. All four estimated models are consistent with Equation (2), and the difference is that each one has unique definition for a proximate bus stop. The following radii for proximity are estimated: 50 m, 100 m, 150 m, and 300 m.

Results from the estimation of Equation (2) for the 50 m, 100 m, 150 m, and 300 m radii are presented in Table 3. In the interest of brevity, only estimates for $I\{\text{Bus stop close}\}$ are reported

in Table 3 as the remainder of coefficient estimates is consistent with the results in Table 2. Testing various radii for proximity reveals that better accessibility to public transportation commands a premium which diminishes relatively fast with distance. Housing units located within 50 meters from a bus stop sell at 1.1 percent higher prices, but statistical significance seems to disappear already beyond 50 meters. Interestingly, the coefficient for 300 m radius indicates that transactions within 300 m radius from a bus stop are discounted 1.4 percent relative to observations that are located farther away. At this point it is important to notice that only 5 percent of the housing transactions are not located within 300 meters from a bus stop, potentially resulting in a bias. Thus, it is likely that the estimated negative price impact cannot directly be associated with proximity to a bus stop, but rather captures price impact from other factors.

Table 3: Estimated price impact, Equation (2)

Radius for close proximity:	50 m	100 m	150 m	300 m
Variable	Coefficient (t-stat)	Coefficient (t-stat)	Coefficient (t-stat)	Coefficient (t-stat)
I{Bus stop close}	0.011 *** (3.0)	0.000 (0.2)	0.004 (1.3)	-0.014 ** (-2.1)
Year indicators:	Included (4 variables)			
Sub-market indicators:	Included (31 variables)			
Adjusted R ² :	90.98%	90.97%	90.97%	90.97%
Observations:	12,449	12,449	12,449	12,449

Notes: This table presents results from the least squares estimation of Equation (1) for the 50 m, 100 m, 150 m and 300 m radii. The dependent variable is Price, logged. The coefficient for I{Bus stop close} indicator variable indicates the estimated price impact of proximity to a bus stop. T-statistics corresponding to the coefficients are reported in parentheses. *** and ** designate statistical significance for the estimated coefficients at the 1% and 5% levels, respectively.

It is reasonable to assume that price impact from proximity to a bus stop may vary between different locations. Thus, to investigate interactions between distance to a bus stop and location in different traffic related zones of urban form, the third and fourth specifications of the hedonic model were estimated. The third specification is consistent with Equation (1) with the difference that six interaction terms are included to capture the joint impact of each traffic related zone and distance to bus stop. Also interaction term *Dist to bus stop*Dist to CBD* is included to capture if the price impact from the distance to a bus stop differs with the distance to Tampere Central Square. The fourth estimated specification of the hedonic model is consistent with Equation (2), but with the difference that six interactions terms are included to capture the joint impact of each included zone indicator and the indicator variable for a proximate bus stop. Results from the estimations of the third and fourth model specifications suggest that price impact may vary between traffic related zones, but due to inconsistencies drawing reliable conclusions based on the results is difficult. The issue behind the inconsistent results is likely to derive from that the third and fourth model specifications divide the full data sample into several subgroups. This results in too small and unevenly distributed subsamples, potentially introducing a bias in the results.

4. Conclusions and Discussion

Although economic consequences are an essential dimension in decision making, yet little is known about the impact of accessibility to bus transportation on housing values. In this study, the void in knowledge was addressed investigating the bus transportation related housing price impact in Tampere, Finland. An empirical strategy utilizing fixed-effect hedonic pricing models was applied.

Results from the estimations indicated that there are statistically significant valuation differences between traffic related zones. The analysis was performed relative to *Intensive public transportation zone*, and estimates revealed that housing prices are relatively highest in the Pedestrian zone, usually indicating location in downtown areas. In Pedestrian zone, housing prices were estimated to be 12.5 percent higher than in Intensive public transportation zone. In Fringe zone, usually located in close proximity to downtown areas, the premium was estimated to be 9.3 percent, in Suburban center zone 2.7 percent, and in Private car zone 2.1 percent relative to Intensive public transportation zone. While, housing units located in Public transportation zone with weaker public transportation connections than in Intensive public transportation zone sell at 2.3 percent lower prices. In an attempt to capture the price impact of distance to the closest bus stop with a continuous *Distance to bus stop* variable, no statistically significant price difference was found. However, testing another model specification utilizing indicator variables, a premium of 1.1 percent was found for housing units located no farther than 50 meters from a bus stop. *Distance to CBD* (Tampere Central Square) was estimated to be an important determinant for housing prices as one kilometer increase in distance results commands 4 percent depreciation in housing values.

The estimation results are in line with assumptions, given that Tampere is a relatively monocentric city with notably extensive bus transportation network; almost every bus line passing through the city center, and 95 percent of the housing transactions being located no farther than 300 meters from the closest bus stop. Due to the great coverage and service frequency of public bus transportation, the CBD is relatively easy to access from anywhere within the city limits. Thus, in Tampere, the distance to CBD seems to be a more important determinant in terms of accessibility than location of the closest bus stop. Valuation of traffic related zones is also mainly consistent with the assumptions as housing units located in zones with more diverse amenities and better bus connections are higher appreciated, with the exception that housing units in Private car zone sell at higher prices than units in Intensive public transportation zone. However, this observation is logical as Private car zone can be associated with comfortable and secure suburban neighborhoods where owner-occupied single-family houses are the predominant form of housing. In this kind of neighborhoods, bus transportation is of less importance as wealthier suburban residents often choose to use their own cars.

This study is the first of its kind investigating the impact of accessibility to bus transportation on housing values in the largest city outside the capital region of Finland. The results do not provide any big surprises but rather confirm authors' presumptions. However, as there are significant differences between cities, some limiting factors should be taken into account when

interpreting the results. Price impact on residential property values was studied only in Tampere, Finland, and it is important to notice that the city structure, extensive coverage of the bus network, local market conditions, and other potential differences between cities may have a notable impact on the outcomes. Thus, more studies are needed before the results may be generalized across other geographical locations. In this study, the price impact was studied using Euclidean distance between the housing unit and bus stop. However, in reality, the accessibility to a bus stop is a much more complicated phenomenon than distance measured as the crow flies (Kang, 2015).

To improve the analysis, it might be useful to use a more advanced approach to define accessibility in further research. For example, accessibility could be defined more precisely taking into consideration the actual characteristics of the surrounding neighborhood. The analysis could also be extended to cover more detailed information on which bus lines serve the proximate bus stop, how often the busses arrive, which areas can directly be accessed via the bus stop, and what is the average driving time to the destination. Adding these above mentioned dimensions in the analysis would allow better understanding of the actual accessibility and its impact on housing values. Also alternative empirical strategies, such as geographically weighted regression (GWR) or combining matched sample methodologies with the hedonic regression, could be applied in an attempt to improve the analysis.

The evidence gained in this study can be utilized when striving for more viable and sustainable cities. Understanding the influence of accessibility to bus transportation on housing values should be of interest to a wide range of city planners, policymakers, and community stakeholders.

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Towards an Integrated Value Adding Management Model for FM and CREM

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Abstract

Purpose: To present an integrated process model of adding value by Facilities Management (FM) and Corporate Real Estate Management (CREM) that is a generalisation of existing conceptual frameworks and aims to be a basis for management of added value in practice.

Background: The growing research on the added value of FM and CREM over the last decade has resulted in the development of several conceptual frameworks and the collection of much empirical data in practice. However, the practical application of current knowledge has shown to be limited and difficult. The reasons seem to be that the different frameworks are too complex and lack of common terminology and clear operationalisations of intervention-impact relationships.

Approach (Theory/Methodology): A generalised Value Adding Management process model is developed based on a common cause-effect model identified in existing conceptual frameworks combined with the basic process model of input → throughput → output. The proposed model consists of interventions as input, management of implementation as throughput and added value as output/outcome.

Results and practical implications: The Value Adding Management model provides a simple framework which aims at supporting the practical management and measurement of added value. A typology with six types of FM/CREM interventions is developed from earlier research. The concept of Value Adding Management is investigated and the 12 most important added value parameters are identified.

Research limitations: The process model still has to be tested on its empirical validity and practical applicability. This is being done and will be presented in a forthcoming book on how to manage and measure value adding by FM and CREM.

Originality/value: The Value Adding Management process model condensates research in an original and simple model with the potential to make value adding management more applicable in practice.

Keywords: Facilities Management, Corporate Real Estate Management, Interventions, Value Adding Management, Added Value.

1. Introduction

Facilities Management (FM) and Corporate Real Estate Management (CREM) are two closely related and relatively new management disciplines with developing professions worldwide and which attract increasing academic attention. Both disciplines have from the outset had a strong focus on controlling and reducing cost for property, work space and related services. In recent years there has been a change towards putting more focus on how FM/CREM can add value to the organisation. The growing research on the added value of FM and CREM has resulted in the development of several conceptual frameworks and collection of much empirical information. However, the practical application of this knowledge has shown to be limited and difficult. The reasons seem to be that the different frameworks are too complex and lack of common terminology and clear operationalisations of input-output/outcome relationships.

The purpose of this paper is to present an integrated process model of adding value by FM and CREM which builds on existing conceptual frameworks and aims to be a basis for value adding management in practice. The paper is related to a forthcoming book, where the model is further explained and validated. It is the result of work in a EuroFM research group established in 2009. The paper is mostly conceptual, but it is based on a huge amount of research and empirical evidence.

2. Conceptual Model

2.1 Existing Conceptual Frameworks

When the research group began there were 3 conceptual frameworks that formed the starting point. One framework was the FM Value Map developed in Denmark by Jensen (2008 and 2010). The other frameworks were more related to CREM. One CREM framework was developed in Finland by Sarasoja – then Lindholm (Lindholm and Leväinen, 2006). The other was developed in the Netherlands by De Vries (De Vries et al., 2008). A fourth framework was later developed in the Netherlands by Den Heijer (2012) - partly based on the framework of De Vries, but redesigned in a different form and extended with various other value parameters.

The FM Value Map and the framework by De Vries both include a basic process model based on input → throughput → output, but in a different way. In the FM Value Map the process model refers to processes in FM and not in the core business, with input being FM resources, the throughput being FM processes and output being FM provisions. The logic of the FM Value Map is that the FM provisions as outputs can lead to different types of outcomes i.e. impacts on added value parameters related to core business and the surroundings and various stakeholders. The distinction between FM as a support function to a core business is a fundamental part of much theory on FM – although not undisputed. This distinction is even included in the definition of FM in

the first European FM standard (CEN, 2006) using the term primary activities as representing the core business.

In the framework of De Vries the process model is related to the overall business organisation and business processes and various stakeholders as well; there is no distinction of a separate CREM process as such. The inputs are divided in 5 general business resources: Human Resources, Technology, Information, Capital, and Real Estate, referring to real estate as the fifth resource (Joroff et al., 1993). Embedded in the process model is a brief overview of real estate interventions that may lead to different types of influences (added values) on the business process and business outputs. The model can be seen as a cause-effect model similar to the outputs leading to impacts in the FM Value Map. The framework of Anna-Liisa Sarasoja does not in a similar way include a process model, but it is basically structured as a cause-effect model with real estate decisions and operation leading to different types of added values that cumulate into increased shareholder value.

2.2 The Value Adding Management Model

In the conceptual frameworks mentioned above a general process model can be recognized:

Input → Throughput → Output → Outcome → Impact = Added Value

We can also identify an underlying cause-effect model that is included in all the four conceptual models with different wordings as shown in Table 1.

Table 1: Cause-effect model in the 4 conceptual frameworks

Framework	Cause	Effect
<i>FM Value Map</i>	<i>Provisions / Output</i>	<i>Impact / Outcome</i>
<i>Sarasoja</i>	<i>Real estate decisions and operation</i>	<i>Added Value</i>
<i>De Vries</i>	<i>Real estate intervention</i>	<i>Influence / Added Value</i>
<i>Den Heijer</i>	<i>Real estate projects / Input</i>	<i>Added Value / Performance</i>

By combining the general process model with the cause-effect model and including value adding management as the intermediary between cause and effect we can define the generalised Value Adding Management process model: Intervention → Management → Added Value.

Intervention is used as the general term for cause and Added Value is used as the general term for effect. This model is very simple and combines essential aspects of the different conceptual frameworks supplemented with the management of implementing the intervention to ensure that the FM/CREM interventions lead to added value for the organisation. In relation to the general process model the focus in the generalised Value Adding Management process model is on how output by appropriate management can lead to outcome and added value.

This is equivalent to: Decision on type of change → Implementation → Outcome/Impact.

And also to: What → How → Why.

What is the kind of change and the improvement FM/CREM intends to make to add value; *how* is the way FM/CREM manages the change and implements the improvement and *why* is the benefit the core business organisation is expected to achieve i.e. the positive outcome of benefits versus sacrifices in terms of costs, time and risks.

The three elements in the Value Adding Management model as presented above can be seen as “black boxes”. In the following section we will open each of these black boxes and reveal what they contain in a FM and CREM context.

3. Opening the Black Boxes

3.1 FM and CREM Interventions

This sub-section explains the first part of the generalised Value Adding Management model called “Intervention” or “Decision on type of change”. It presents a typology of FM and CREM interventions based on earlier research consisting of the following six types of FM and CREM interventions:

1. Changing the physical environment (on different scale levels: portfolio, building, space)
2. Changing facilities services
3. Changing the interface with core business
4. Changing the supply chain
5. Changing the internal processes
6. Strategic advice and planning

Changing the Physical Environment

The physical environment is essential to both FM and CREM. It includes buildings, internal and external spaces, technical services (installations), indoor climate, fitting out, furniture, workplaces, technology, artwork and ambience. Typical examples of changing the physical environment include:

- Moving to another location (new or existing building)
- New building
- Rebuilding, refurbishment or adaptive re-use i.e. conversion to new functions
- Changing workplace layout, e.g. conversion of a cellular office with personal desks to an activity-based work setting with shared use of a variety of task-related workspaces
- Changing appearance, e.g. to support corporate branding

Changing Facilities Services

The facilities services are the operational FM activities. In the European standard on taxonomy for FM (CEN, 2011) the facilities services are divided in demand related to Space & Infrastructure and demand related to People & Organisation with both categories sub-divided in standardised facility products as shown in Table 2. The standardised facility products Space and Workplace in the table are partly overlapping with Changing the physical environment, but the physical environment basically concerns tangible artefacts, while the facilities services mostly concerns intangible service activities.

Table 2: FM taxonomy with standardised facility products (CEN, 2011)

<i>Demand related to</i>	<i>Standardised facility product</i>
<i>Space & Infrastructure</i>	<i>Space (Accommodation)</i>
	<i>Outdoors</i>
	<i>Cleaning</i>
	<i>Workplace</i>
	<i>Primary activities specific</i>
<i>People & Organisation</i>	<i>HSSE (Health, Safety, Security and Environment)</i>
	<i>Hospitality</i>
	<i>ICT (Information and Communication Technology)</i>
	<i>Logistics</i>
	<i>Business Support (Management Support)</i>
	<i>Organisation specific</i>

Changing the Interface with Core Business

When organisations reach a certain size and complexity, FM and CREM are typically established as separate functions or departments. The interface between the core business and FM/CREM is defined specifically in each organisation and is not static. If the FM/CREM function is successful, it will in many cases get the opportunity to increase its area of responsibility. This is often part of a centralisation of the responsibility from several parts of the core business organisation to the FM/CREM function, thereby creating opportunities for economies of scale.

Changing the Supply Chain

FM is in most cases organised as a mixture of an in-house FM-function and a number of external providers of facilities services, which constitutes a FM supply chain. The situation is to some degree similar for CREM, but the CREM supply chain is more project-related and mostly consists of consultants, designers and contractors. Changes in the supply chain are primarily changes in the delivery process, but they often also have consequences for the incentives for the different parties and the management of the mutual relationships between the parties. The number of external providers varies a lot depending on the type of company and the sourcing strategies. Outsourcing in FM has over the last decades been constantly increasing in most countries and is a common way to achieve cost reductions. Even though the general trend is towards more outsourcing in most countries, there are also many examples of insourcing of former outsourced services.

Changing the Internal Processes

What we deal with here is increasing the efficiency of operational processes within a specific organisation without necessarily changing, neither the product, nor the supply chain. The organisation can be in-house or an external provider. Within management theory and practice there are a number of concepts aimed at increasing productivity and process efficiency, for instance Total Quality Management, Business Process Re-engineering, Benchmarking and Lean Management. Typical elements in such concepts are eliminating waste, implementing new technological solutions and optimising the work flow. Many companies conduct projects by using such concepts and the FM function is often included in the project. Many provider companies also work systematically with developing process innovations. This is also the case for some of the larger in-house organisation.

Strategic Advice and Planning

Strategic advice and planning are essential elements in the strategic and tactical activities of FM and CREM. The areas for strategic advice and planning can cover many different aspects and they will typically change over time according to what is of strategic importance for the company. A typical area of strategic advice to top management concerns the development of a long-term strategy for the corporate property portfolio. This requires a profound and up to date understanding of the overall corporate strategy to identify the future demand for property and close dialogue with evaluation of options, scenarios and proposals concerning the future supply of property. Another typical area is investment planning and feasibility studies, which concerns decision support on choosing between alternative options for fulfilling a need for changes in the capacity of space or similar. This can for instance be whether the company should extend existing facilities, relocate, build new building, sell or buy property, rent or rent out space.

3.2 Value Adding Management

This sub-section explains the second part of the generalised Value Adding Management model called “Management” or “Implementation”.

The term “Value Adding Management” and related terms are widely used in business and management literature. In manufacturing related literature “Value Adding Management” or VAM is often used in a way close to Lean Management with a focus on eliminating non-value adding or “waste” activities. However, VAM is also seen as part of an overriding strategy, where the corporate mission is *what* and VAM is *how* (Anonymous, 2014). This resembles our generalised Value Adding Management model, but there is no mentioning of *why*, except indirectly with including “value adding” in the term. The industrial consultant Carlo Scodanibbio even calls VAM the philosophy of the second industrial revolution and the guiding light for the year 2000 industries (Scodanibbio, 2014).

It relation to FM and CREM essential aspects of VAM are strategic alignment between FM/CREM and core business and stakeholder management and relationship management as part of the

implementation of changes. Here we will solely focus on strategic alignment. Aligning, in an active sense, implies moving in the same direction, supporting a common purpose, being synchronized in timing and direction, being appropriate for the purpose and in a passive sense, the absence of conflict (Then et al., 2014).

Figure 1 connects the terms alignment and added value to show that corporate real estate only adds value when it supports the organisational objectives. It shows that alignment of the accommodation and building related facilities and services requires a thorough understanding of the organisational strategy and its structure, culture, primary processes and so on. When the FM/CREM department develops its mission, vision and strategy, this should be done in connection to the mission, vision and strategy of the organisation. FM/CREM interventions should not only be checked on its impact on FM/CREM performance and organisational performance, but also on its impact on attaining organisational goals. A better performance does not per definition deliver added value. For instance, if an FM intervention results in a higher ranking on “green buildings” but the organisation was fully satisfied with the original ranking, this higher ranking does not add any value to the organisation.

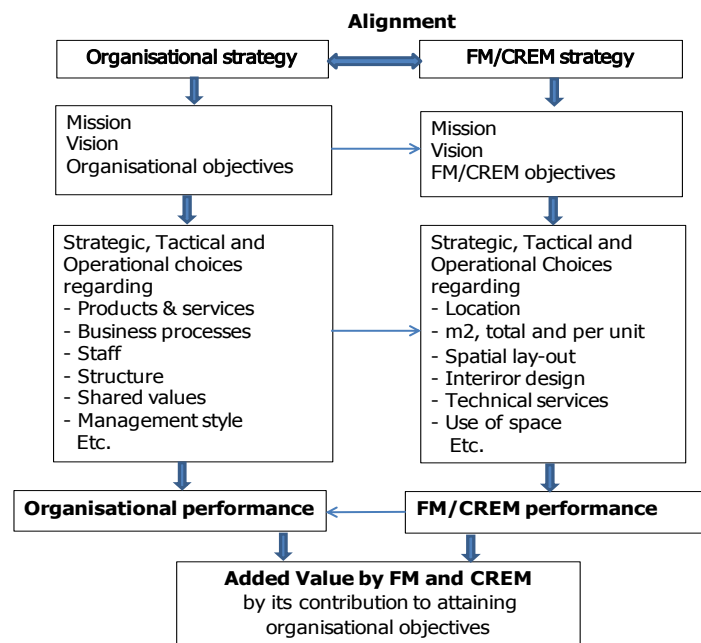


Figure 1: Connections between alignment and adding value (Van der Voordt, 2014)

3.3 Added Value Parameters

This sub-section explains the third part of the generalised Value Adding Management model called “Added Value”. Table 3 presents an overview of the value parameters that were discussed in various studies and which have been classified in the six categories of performance measurement mentioned by Bradley (2002). With the division of the category Organisational development in 5

sub-groups table 3 provides 10 different value parameters with slightly different names. Remarkably the list of parameters by De Vries et al. (2008) is lacking in this list.

Table 4 presents a comparison of the 4 models mentioned in section 2. One difference is that it uses a more recent version of the model by Sarasoja, which includes Supporting environmental sustainability (Lindholm and Aaltonen, 2012). The different value parameters have been categorised under the four headings People, Process, Economy, and Surroundings.

*Table 3: Different value parameters classified into the six categories
(Riratanaphong and Van der Voordt, 2015)*

<i>Bradley (2002)</i>	<i>Nourse and Roulac (1993)</i>	<i>De Jonge (1996)</i>	<i>Lindholm & Gibler (2005); Lindholm (2008)</i>	<i>Van Meel et al. (2010)</i>	<i>Den Heijer (2011)</i>	<i>Van der Zwart and Van der Voordt (2013)</i>	<i>Jensen et al. (2012)</i>
<i>1. Stakeholder perception (employee satisfaction)</i>	<i>Promoting HRM objectives</i>	-	<i>Increasing employee satisfaction</i>	<i>Attracting and retaining talented staff</i>	<i>Supporting user activities</i> <i>Increasing user satisfaction</i> <i>Improving quality of place</i>	<i>Increasing user satisfaction</i>	<i>Satisfaction</i>
<i>2. Financial health</i>	<i>Capturing real estate value creation of business</i>	<i>Increasing of value</i>	<i>Increasing the value of assets</i>	-	<i>Increasing real restate value</i>	<i>Improving finance position</i>	-
<i>3. Organisational development</i>	<i>Flexibility</i>	<i>Increasing of flexibility</i>	<i>Increasing flexibility</i>	<i>Increasing flexibility</i>	<i>Increasing flexibility</i>	<i>Improving flexibility</i>	<i>Adaptation</i>
	<i>Facilitating managerial process and knowledge transfer</i>	<i>Changing culture</i>	-	<i>Encouraging interaction</i> <i>Supporting cultural</i>	<i>Supporting culture</i> <i>Stimulating collaboration</i>	<i>Improving culture</i>	<i>Culture</i>
	<i>Promoting marketing message</i> <i>Promoting sales & selling process</i>	<i>PR and marketing</i>	<i>Promoting marketing and sales</i>	<i>Expressing the brand</i>	<i>Supporting image</i>	<i>Supporting image</i>	-
	<i>Facilitating and controlling production, operation and, service delivery</i>	<i>Risk control</i>	-	-	<i>Controlling risk</i>	<i>Controlling risk</i>	<i>Reliability</i>
	-	-	<i>Increasing innovation</i>	<i>Stimulating creativity</i>	<i>Stimulating innovation</i>	<i>Increasing innovation</i>	-

<i>Bradley (2002)</i>	<i>Nourse and Roulac (1993)</i>	<i>De Jonge (1996)</i>	<i>Lindholm & Gibler (2005); Lindholm (2008)</i>	<i>Van Meel et al. (2010)</i>	<i>Den Heijer (2011)</i>	<i>Van der Zwart and Van der Voordt (2013)</i>	<i>Jensen et al. (2012)</i>
4. <i>Productivity</i>	-	<i>Increasing productivity</i>	<i>Increasing productivity</i>	<i>Enhancing productivity</i>	<i>Supporting user activities</i>	<i>Improving productivity</i>	<i>Productivity</i>
5. <i>Environmental responsibility</i>	-	-	-	<i>Reducing environmental impact</i>	<i>Reducing the footprint</i>	-	<i>Environmental</i>
6. <i>Cost efficiency</i>	<i>Occupancy cost minimization</i>	<i>Cost reduction</i>	<i>Reducing costs</i>	<i>Reducing costs</i>	<i>Decreasing costs</i>	<i>Reducing costs</i>	<i>Cost.</i>

Table 4: Comparison of added value parameters in four models

	<i>A. Jensen et al., 2008</i>	<i>B. Lindholm and Aaltonen, 2012</i>	<i>C. De Vries et al., 2008</i>	<i>D. Den Heijer, 2011</i>
Core business				
<i>People</i>	<i>Satisfaction Culture</i>	<i>Increase employee satisfaction</i>	<i>Image Culture Satisfaction</i>	<i>Increasing user satisfaction Supporting image Supporting culture</i>
<i>Process</i>	<i>Productivity Reliability Adaptability</i>	<i>Increase innovation Increase productivity Increase flexibility</i>	<i>Production Flexibility Innovation</i>	<i>Increasing flexibility Supporting user activities Improving quality of place Stimulating innovation Stimulating collaboration</i>
<i>Economy</i>	<i>Cost</i>	<i>Increase value of assets Promote marketing and sale Reduce cost</i>	<i>Cost Possibility to finance Risk control</i>	<i>Controlling risk Increasing real estate value Decreasing cost</i>
Surroundings	<i>Economic Social Spatial Environmental</i>	<i>Supporting environmental sustainability</i>		<i>Reducing the footprint</i>

The parameters related to People include (employee) satisfaction in all models. Model A also include “Culture”, while both model C and D include “Culture” as well as “Image”. Model B only includes “Increase employee satisfaction” under People. This model does as the only model include “Promote marketing and sale” placed under Economy. This parameter can be seen as an economical expression of “Image”, understood as brand. All four models include at least three parameters for Process with many overlaps. The differences can partly be seen as different degrees of sub-dividing. In relation to Economy, model A (the FM Value Map) only includes the parameter “Cost”, while the three other more CREM based models include parameters for “Value of real estate”, “Value of assets” or “Possibility to finance”. The parameter “Controlling risk” in model D is defined as

related to financial goals, but it is also strongly related to the Process parameter “Reliability” in model A. In model C “Risk control” is included as well, partly related to reducing financial risks, but also to improving health and safety. Model A was the first model to include parameters related to Surroundings, including the “Environmental” parameter. The more recent CREM based models B and D also include a parameter for “Environmental sustainability” or “Reducing the footprint”.

Based on the parameters in Table 3 and 4 we have decided to use the 12 value parameters listed in Table 5. All the parameters in Table 3 and 4 are more or less included, but the names of the parameters have been harmonised and Corporate Social Responsibility has been added. The parameters are like in Table 4 organised with four headings, but the heading Process has been changed to Process and Product.

Table 5: Added value parameters

Group	Parameter
<i>People</i>	<i>Satisfaction</i>
	<i>Image</i>
	<i>Culture</i>
	<i>Health and Safety</i>
<i>Process and Product</i>	<i>Productivity</i>
	<i>Adaptability</i>
	<i>Innovation and Creativity</i>
	<i>Risk</i>
<i>Economy</i>	<i>Cost</i>
	<i>Value of Assets</i>
<i>Societal</i>	<i>Sustainability</i>
	<i>Corporate Social Responsibility</i>

4. Discussion and Conclusion

Figure 2 shows the Value Adding Management model from section 2 with the 6 types of interventions from sub-section 3.1, the different aspects of VAM from sub-section 3.2 and the 12 added value parameters from sub-section 3.3. The model is seen as an integrated model for FM and CREM, which is generic for all kinds of businesses and for all types of property and facilities.

In order to be able to define the added value of an intervention by FM/CREM, it is important to measure the outcomes and impact of any intervention, ex-post and preferably also ex ante, as input to a business case (Van der Zwart and Van der Voordt, 2015). Clear performance indicators make it possible to assess how well people or facilities perform. The outcomes can provide the inspiration to achieve higher levels of effectiveness, efficiency, quality, and competitiveness. As such, performance measurement is an important aid for making judgments and decisions, which can help managers to answer five important questions: 1) where have we been; 2) where are we now; 3)

where do we want to go; 4) how are we going to get there; and 5) how will we know that we got there (Lebas, 1995). Besides the need to operationalise the various value parameters in SMART performance indicators (Specific, Measurable, Assignable, Realistic and Time-related), performance measurement should be precise about the performance of *what*, e.g. people, facilities, or services.

Apart from clear performance indicators, it is also important to be able to define the causes of high or low performance, and to understand which changes are needed to improve what kind of performance. De Vries et al. (2008) concluded that cause-effect relationships are difficult to prove, due to the impact of many interrelated input factors, and the way interventions are implemented. It is our ambition in our further research to assess the 12 selected value parameters on what we know, what we still need to know, and what Key Performance Indicators could be applied to measure the different added values (Jensen and Van der Voordt, 2016).

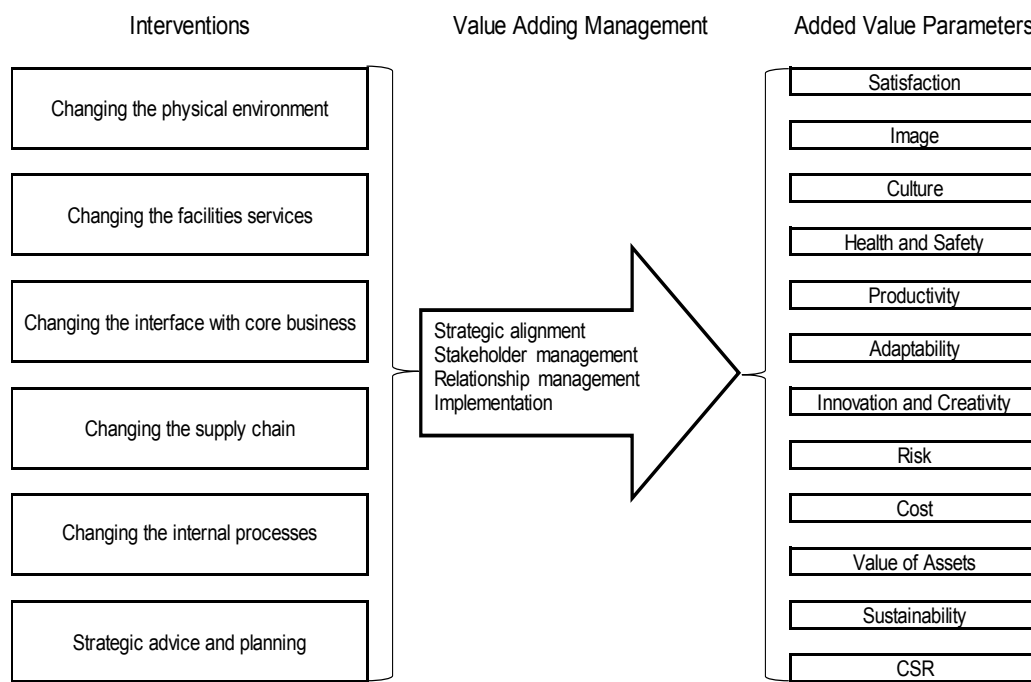


Figure 2: Added Value process model with types of interventions and added value parameters

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Managing Network Risks in Health Facilities

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Abstract

Health facilities play a crucial role in maintaining healthcare services to the community during an extreme weather event. Health facilities managers operate within a wider network of organisations which include emergency services, health resource suppliers, local authorities, external health agencies and governmental organisations. Their response to an extreme weather event depends significantly on their ability to manage the network risks which may arise between actors in this complex system. Yet existing research has tended to look at facilities managers in isolation. Through an in-depth case study of how health services in the State of New South Wales, Australia would respond to an extreme weather event, the interface risks between these various agencies are explored from a facilities management perspective. An analysis of 139 documentary sources which would dictate the inter-agency response shows that health facilities managers face numerous hidden risks arising from overlapping, complex and unresolved governance conflicts between the agencies on which they depend. It is concluded that these interface risks can be reduced if facilities managers employ a number of strategies. These include: mapping hospital dependency on other agencies; resolve overlapping operational boundaries with other agencies; undertaking proactive risk reduction for critical external support infrastructure; and better understanding potential conflicts with external agencies in responding to an extreme weather event.

Keywords: Facilities management, hospitals, risk, inter-agency, governance

1. Introduction

Using systems theory, Loosemore et al. (2012) provided empirical evidence to show that if healthcare facilities are to become more resilient to extreme weather events (EWEs), they cannot be treated in isolation from the wider systems in which they exist. EWEs are defined as weather patterns such as heatwaves, storms and floods that exceed a particular threshold and deviate significantly from mean climate conditions (Linnenluecke and Griffiths 2010). These interdependent systems include other organisations such as: the police, the army, the fire services; water, electricity and gas authorities; off-campus hospital suppliers; polyclinics; aged care facilities; and other critical service providers. Although the health facilities management literature acknowledges that the health system is complex, it provides little insight into the interface risks associated with the coordination and integration of all these organisations when the system is under stress. The ability of these various organisations to effectively coordinate with each other before, during and after an EWE can have a direct impact on a hospital's ability to cope. For example, records from the 1997 heat wave in Adelaide, South Australia, show that hospital computers overheated and failed and that outages occurred in water supply, air-conditioning and energy supply (Emergency Management Australia 1998). The 2005 Sydney heat waves had similar impacts and particularly affected the elderly and other vulnerable populations such as the obese and chronically ill, causing increased hospital admissions relating to heatstroke and cardio vascular diseases. This is not a problem unique to Australia. For example, in 2007 a tornado hit Greymouth in the South Island of New Zealand cutting electricity lines, damaging buildings and flooding access roads to many critical facilities (New Zealand Ministry of Civil Defence and Emergency 2007). Many other EWEs such as Hurricane Sandy in the USA in 2012 and the UK floods in 2007, have highlighted the vulnerability and inherent interconnectedness of critical infrastructure such as hospitals, power generation, water and transport networks, leading to calls for greater investment to make these systems more resilient to these emerging risks (Gardiner 2013, Committee on Climate Change 2014).

This intricate interdependency on other infrastructure systems indicates that health facilities managers have to operate within a complex system containing 'systemic risks' which propagate through numerous pathways, spreading quickly and rapidly, in non-linear and unpredictable ways (Koubatis and Schönberger 2005). Helbing (2013: 51) defines 'systemic risk' as "the risks of not just having statistically independent failures but interdependent so-called 'cascading' failures in a network of N interconnected system components". In other words, systemic risks result from looped connections between different system components (sub systems), leading to localised initial failures spreading and potentially inflicting unbounded damage. As White (1995), Jaafari (2001), Stahl, et al (2003) and Koubatis and Schönberger (2005) argue, complex systems are inherently unstable and characterised by multiple elements which are so interlinked that it is rarely possible to trace a risk event back to one singular event. This inherent instability arises from the important property of 'self-organization' (the ability of a system's connections and interdependencies to change, adapt and develop on their own without the influence of external managers). Systems researchers have shown that the property of self-organisation ensures that complex systems tend to settle at a 'critical edge' where a small change in the system can lead to catastrophic changes in the overall system through 'cascading

interdependencies' which exist between different parts of a system. This property of systems is called 'self-organised criticality' and Kampmann (1999) argues that the world is made up of complex systems which may appear under control on the surface, but exist in a state self-organised criticality which makes sudden catastrophic collapses in response to external disturbances almost inevitable.

It is within this context that the paper aims to explore the systemic network risks which facilities managers face in the health sector. Responses to EWEs are studied as these events represent a real and growing threat to the health sector and address an important yet missing inter-organisational dimension in the facilities management and disaster management debate, which hitherto has been largely confined to intra-organisational issues.

2. Interface risks and extreme weather events

Numerous researchers such as Ansell and Gash (2008), have recognised the challenges of how multiple interdependent organisations mobilise, co-ordinate and control their actions and resources to respond to, cope with and recover from external threats such as an EWE. The earliest work in this field is attributed to Prince (1920), who derived a 'social theory' to explain human response to disaster. Later, Mileti et al. (1975) introduced the concept of the "disaster life cycle" and established the fundamental concepts of mitigation, preparedness, response and recovery used in most contemporary disaster management plans and facilities management literature. Drabek (1986) refined this work and introduced the concepts of emergent behaviour and human systems in disaster response, igniting the current debate over the validity of the centralised or bureaucratic model promoted in disaster management. Contemporary research into multi-agency responses to natural disasters (eg. Houghton et al. 2006; McMaster and Baber 2009) is concerned with the challenges faced by multi agencies in adapting their governance boundaries from standard operating procedures to accommodate the broader dynamic inter-agency interdependencies required in a disaster or crisis. During a threat such as an EWE, multiple agencies are required to change their modes of operation, to perform different functions and to work on multiple tasks simultaneously and under considerable time pressures. This requires path dependencies to be challenged and a certain degree of adaptive capacity to break with the 'normal' routines that are known to work when the system is not under threat.

From an interface risk management perspective, contemporary disaster management theory can be divided into two schools of thought. The first emphasises the importance of a centralised authority for a successful disaster response and the value of agreed, well-practiced operating procedures (Drabek and McEntire 2002). The second acknowledges emergent behaviours and is orientated towards decentralised or self-organising models operating on the basis of cooperation and collective problem solving (Mendonca et al. 2007). Recent research has also raised doubts about the effectiveness of the traditional command and control model (Mendonca et al. 2007, Kapucu and Arslan 2010). It is argued that while a central coordinating authority and pre-determined disaster management plans can be of value, it can also reduce the opportunity for improvisation and adaption to novel conditions which might typically arise during an EWE. Recent research is showing that the effectiveness of disaster response is highly dependent on

pre-existing relationships between responding agencies established prior to the event (McMaster and Baber 2008; 2009, Department of Homeland Security 2012). The body of research outlined above indicates the importance of facilities managers establishing and maintaining relationships well in advance of an EWE event, yet Heng and Loosemore's (2011) research shows that this can be problematic because facilities managers are often seen as trivial and marginalised from central social networks in and around healthcare operations.

3. Methods

To investigate the interface challenges that hospital facilities management might face in managing this network of interactions, we conducted an in-depth analysis of the complex inter-agency governance structure responsible for managing healthcare delivery in the state of New South Wales, Australia. Australia comprises six states and two internal territories. All states and internal territories have their own parliaments and administer themselves, working in partnership with the Federal Commonwealth Government. Each state also retains the power to make their own laws over matters not controlled by the Commonwealth and have their own constitutions, as well as a structure of legislature, executive and judiciary. In terms of health services, the Federal Commonwealth Government provides leadership, financing, research and national information management around health policy while the states and territories are largely responsible for the delivery of public health care services and the management of healthcare workers in the public and private sectors. The states and territories deliver public acute and psychiatric hospital services including school and child health programs. Residential aged care is financed and regulated by the Federal Commonwealth Government and is outsourced mainly to the non-government sector (religious, charitable and for-profit providers). The Commonwealth, states and territories jointly fund and administer community care (such as delivered meals, home help and transport).

The state of New South Wales (NSW) provided an ideal context in which to study interface risks in this system. It is Australia's most populous state, with a population of about 7.5 million people served by about 230 public hospitals over an area of 809,444 km² which provide a wide range of other connecting services including emergency care, elective and emergency surgery, medical treatment, maternity services and rehabilitation programs. In addition to the Ministry of Health, the NSW Health service structure includes Local Health Districts, statutory health corporations and affiliated health organisations. New South Wales public health services include public hospitals, community, family and children's health centres, ambulance services and an extensive range of specialty services including mental health, dental, allied health, public health, Aboriginal health and multicultural health services. There are 15 Local Health Districts that are responsible for providing health services in a wide range of settings, from primary care posts in the remote outback to metropolitan tertiary health centres. The Ambulance Service of NSW is responsible for providing responsive, high quality clinical care in emergency situations, including pre-hospital care, rescue, retrieval and patient transport services.

Data about the interagency response boundaries and interactions revolving around healthcare facilities issues were collected using 139 documentary sources which would dictate the inter-agency response to an EWE. These documents included:

- Published governance structures for operating and maintaining public hospitals in New South Wales;
- Hospital, agency and community disaster management plans; government policy and legislation;
- Building control and standards guidance; published agency and government analysis of past EWE disaster responses;
- Annual reports of responding agencies; government inquiries into EWE responses; internal discussion papers;
- Disaster and emergency agency websites.

This data was analysed by cross-tabulating the responsibilities of the various agencies' names in these documents. The focus was to look for gaps and overlaps in their response mechanisms which could compromise the business continuity of a hospital in delivering health care services to communities during and after an EWE. A single case study approach of NSW (albeit with multiple internal dimensions), like any approach, has well-recognised limitations, particularly around representativeness and generalizability (Yin 2009). However, as discussed in the literature reviewed above, the number of potential agencies potentially involved in the response to an EWE and the complexity of interactions requires an in-depth approach to properly understand. Furthermore, in response to potential criticisms around generalizability, Flyvbjerg (2011: 301) argues that "while it is correct that the case study is a detailed examination of a single example, it is not true that a case study cannot provide reliable information about the broader class". Therefore, while the advantage of large samples might be breadth and representativeness, the advantage of case studies is depth and validity.

4. Analysis of interface risks

Our analysis indicated seven critical governance risks that can potentially impact a hospital facilities manager's ability to respond effectively to an EWE. These are:

- Inter-agency cooperation;
- Surge capacity;
- Preparation time;
- Gaining access to and from the disaster field;
- Resolving overlapping operational boundaries;
- Coordinating with agencies external to the health system;
- Resolving potential conflicts between external agencies.

Each of these risks is discussed in more detail below:

4.1 Inter-agency cooperation

In NSW, responsibility for the formulation and maintenance of disaster plans is delegated to 152 local governments which develop individual whole-of-community plans coordinated across the 11 Emergency Management Districts. Responsibility for disaster management of individual hospitals (both public and private) is allocated to 17 Local Health Districts (LHDs) with a different set of operational boundaries. Not only does this complex and overlapping governance landscape create potential coordination problems for facilities managers in preparing and responding to an EWE, it also creates the risk for disaster planning for hospitals to be undertaken in isolation from the whole-of-community disaster plans that are coordinated by Local Government officials.

4.2 Surge capacity

Our analysis indicated that surge capacity is a recurrent problem in hospitals and while financial constraints are often blamed for this, other issues identified in post disaster reports include fragmented governance of surge resources, offsite storage of resources, over-loaded supply chains and poor communication about overflow management.

4.3 Preparation time

Post disaster reports show that hospitals need preparation time to deploy a response team, be sufficiently resourced to receive mass casualties, as well as to assist with the health response during the community's recovery period. It also depends on careful planning to provide sufficient temporary additional treatment space through a range of measures including cancelling elective surgery, diverting emergencies not related to the disaster to other hospitals, and potentially transferring patients.

4.4 Access to and from the disaster field

There is an assumption that access to and from the disaster field will be possible during the course of a disaster response and recovery period. Not only does this assumption rely on surrounding infrastructure remaining operational (for example, roads, helipads or airports), it also relies on transport vehicles and equipment being capable of handling the conditions within the disaster field. However, our analysis indicated that dependency on other overloaded agencies to supply transport and the inability of the available responders to negotiate flooded roadways or rough terrain can significantly affect the effectiveness of hospital responses.

4.5 Overlapping operational boundaries

Our analysis shows that EWEs typically affect a wide catchment area and are likely to be covered by more than one local disaster plan, and in severe cases potentially even some regional or district-based disaster plans. This requires hospitals to be familiar with the procedures and

arrangements contained within multiple disaster plans, and also to build operational relationships with a wide range of stakeholders and responding agencies.

4.6 Funding of asset development

In Australia, the state government will typically own a hospital's physical assets including the site, and through its various agencies, oversee and fund its upgrade or renewal. Individual hospital facilities managers and regional health boards tend to have funding and delegated responsibility to manage the operation including routine maintenance of individual sites and supporting built infrastructure. There are two obvious problems with this arrangement: firstly, the people on the ground with the responsibility for preparing for and responding to an EWE have limited influence over decisions to upgrade or renew their hospital which could affect their ability to respond. Secondly, at a state level, decisions regarding capital expenditure on the upgrade or renewal of assets within an individual site are typically prioritised, with reference to the entire hospital portfolio. What may be of high priority to an individual hospital in its disaster planning may not necessarily be considered so by government at the state level.

4.7 Coordination with agencies external to the health system

Although most health systems attempt to ensure independence through backup systems such as the installation of generators, our analysis showed that hospitals inevitably have to rely on interactions with agencies outside the health sector when an EWE strikes. LHDs have limited influence over the centralised procurement from warehousing facilities supplying support services such as linen, catering, IT or consumable medical supplies within their districts. In the same way, during an EWE, LHDs will have little influence in mobilizing other agency resources. Given that hospitals are not geared to provide their own disaster transport, they are highly dependent on other emergency service agencies to assist with the deployment of medical teams and supplies into the disaster field and also to transfer casualties from the field for treatment in hospital. Therefore, the quality and timeliness of the 'health' response is dependent on the cooperation of other agencies.

4.8 Potential conflict between external agencies and hospital objectives

One major problem for a facilities manager in dealing with an EWE is that external agencies may have conflicting objectives to those of the hospital. For example, records show that local aged care facilities often lack a disaster plan and tend to evacuate their patients and residents to tertiary hospitals during an event such as a flood, to prevent them being cut-off. Not only could patients become stranded en-route, but the arrival of additional vulnerable elderly persons into a hospital at a time when it is already under stress puts undue strain on the response effort.

5. Discussion

Past research on facilities risk management governance issues has taken an intra-organisational focus and the aim of this study was to balance this with inter-organisational insights. The findings add further qualitative evidence to Loosemore et al's (2012) research which argued that hospital facilities management is best conceptualised using a systems perspective that recognises the wider system in which hospitals are placed. The findings also support McMaster and Baber's (2008) and Uhr's (2009) contention that effective inter-agency coordinating is highly dependent on pre-existing relationships between responding agencies established prior to the event. In doing so it has also exposed the potential problems of 'sequential single agency response' highlighted by McMaster and Baber (2009). From a contemporary disaster management theory perspective, our results question the efficacy of the centralised governance school of thought which argues that a successful disaster response depends on the development of agreed, well-practiced operating procedures (Drabek and McEntire 2002). However, our findings also showed that the boundaries defining what each agency will tackle are often confused and are unlikely to adequately consider the dynamic inter-agency interdependencies required to ensure an effective response to an EWE. Furthermore, our research shows that while hospital facilities managers are responsible for managing critical assets during an EWE, they are unlikely to be an integral part of a common operational picture or a shared situational awareness which disaster management researchers like Wickens (2008) advocate. Our research suggests that during an EWE people will need to move outside these procedures and that it is therefore important to acknowledge emergent informal systems and behaviours, and the need for decentralised or self-organising models operating on the basis of cooperation and collective problem solving (Mendonca et al. 2007). In terms of future research, our findings therefore suggest that there is a need to more deeply explore the interaction between formal and informal systems and procedures in disaster response and in particular, how informal processes and procedures can act to support the formal systems that central policy-makers have put in place.

6. Conclusions

The aim of this paper was to explore the systemic network risks which facilities managers face in the health sector. Theoretically, these findings add to the facilities management literature by highlighting the importance of power for facilities managers as determined by their position in the social networks that are defined by disaster management plans. They also highlight the need to develop brokerage and relationship-building skills which are largely ignored in the facilities management literature. While interviews with key stakeholders would provide further valuable insights and while further research is clearly needed into the inter-agency challenges of the facilities management function, the value of this research is that it reveals a set of issues and skills which are not typically covered in facilities management research literature. In particular, it highlights the importance of: adopting a systems perspective in understanding the health system as a whole; understanding the power, politics and economics of governance; stakeholder management; inter-agency relationship building; and understanding the objectives, plans and constraints of other organisational functions (external and internal) which the facilities manager depends on. As evident from our findings, it is important that any future analysis of these issues

should take care not to neglect the social networks in which facilities managers are imbedded and of their power relationships with other disaster management stakeholders.

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Operating Cost Estimation: A Comparison of Methods

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Abstract

Operating costs represent a significant amount of the overall expenditures over the life-cycle of buildings. Therefore, it is a crucial task for all participants involved in the planning process to determine operating costs as early as possible. Accordingly, cost-benefit analyses can be developed and planning alternatives can be evaluated economically. Likewise, costs incurring during the operation of buildings can be monitored and controlled in an iterative process. Consequently, methods for an accurate estimation of operating costs are essential and can serve as a foundation for decision-making and budgeting.

The current approach focuses on the comparison of statistical methods for the estimation of operating costs using empirical data as a basis. Therefore, a sample consisting of 206 occupied facilities located in Germany is employed. The data was gathered in the years 2008 to 2014 from 25 project partners and contains 11 different facility types. Linear and nonlinear regression models and artificial neural network models are developed, specified, and validated. Additionally, categorised cost indicators for the estimation of operating costs are introduced, using the results of the developed statistical models as a basis. All statistical methods are evaluated for their accuracy employing an independent, randomly selected, and representative test sample.

The results show the best estimation accuracy for the nonlinear regression model and the artificial neural network model with mean absolute percentage errors of 15.4% and 16.6% respectively. The minor differences of the measures of performance and quality for both models utilising the same 7 predictor variables indicate correctly specified models. The procedure of model development and the evaluation of the results are presented in detail and may serve as a basis for further research on the estimation of operating costs and the identification of significant predictor variables. The extension of the data sample, the consideration of further facility types, and the implementation of additional statistical methods may be considered by future approaches to improve the accuracy of operating cost estimation.

Keywords: Operating costs, estimation, statistical methods, regression analysis, artificial neural networks

1. Introduction

A significant amount of the financial expenditures over a building's life-cycle are represented by operating costs. Various studies illustrate the financial relevance of these costs and point out the substantial potential of cost savings for property owners and leaseholders. For instance, operating costs for school facilities of between 27.93 and 35.44 Euro/m²*a (per m² usable floor area) are published by Beusker (2003). Accordingly, it is an increasingly important task to determine operating costs as early as possible in the process of planning. This is the only way to develop cost-benefit analyses and evaluate planning alternatives holistically. Likewise, costs incurring during the operation of buildings can be monitored and controlled in an iterative process.

Consequently, methods for the estimation of operating costs under consideration of significant influential variables are essential and can serve as foundation for decision-making and budgeting. Though various statistical methods for the estimation of construction costs and corresponding influential variables are extensively examined and evaluated, there are currently only the studies of Stoy and Kytzia (2006) (office facilities) and Beusker (2013) (school facilities) introducing statistical methods for the estimation of operating costs and evaluating the quality and performance of the developed models.

The current approach develops and evaluates several statistical methods (regression, artificial neural networks, and cost indicators) for the estimation of operating costs. Based on a wide range of possible predictor variables and a data sample of 206 occupied facilities, the procedure of model development is presented in detail including specifications and parameters of the best-fitting model. Significant variables influencing operating costs are identified and validated. Categorized cost indicators for the estimation of operating costs are introduced using the results of model development as a basis. All statistical methods are assessed according to their estimation accuracy employing an independent, randomly selected, and representative test sample. The main objectives of the current study are:

- Development and specification of linear and nonlinear regression models and artificial neural network models.
- Identification of significant variables influencing operating costs.
- Introduction of categorised cost indicators.
- Evaluation of the estimation accuracy of the presented statistical methods.

Chapter 2 gives an overview of the statistical methods that are employed to conduct the current approach and defines operating costs as the response variable of the study. Chapter 3 contains a description of the data sample and includes descriptive statistics of variables serving as basis for the statistical analysis. The development of the statistical models and indicators for cost estimation is presented in Chapter 4. The best-fitting statistical model is specified in detail including relevant parameters. The estimation accuracy of the statistical methods is evaluated by an independent test sample. Before concluding the study in Chapter 6, a summary of the results including a discussion is given in Chapter 5.

2. Methodology

Statistical models are designed to capture and represent the reality as close and accurate as possible in practice and may be used for investigation or prediction (Fellows and Liu, 2008). Regression analysis is a method to determine functional relationships among variables and can be employed for description, model building, estimation, prediction, and for control aims (Chatterjee and Hadi, 2006). In multiple regression the attributes of one response variable depending on several predictor variables are explained by the following generalised relationship (Backhaus, Erichson, and Weiber, 2013):

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_i X_i + \varepsilon$$

where Y is the response variable, β_0 is the constant and β_i are the coefficients, X_i are the predictor variables, and ε is the error term of the regression. The unknown model parameters β_0 and β_i are to be determined from the data as accurate as possible by the so called ordinary least squares (OLS) method. Therefore, the mean squared error term ε (difference between observed and estimated value) for all observations is kept as small as possible.

Regression models for the estimation of costs in the field of construction are utilised since the 1970s. The current study introduces linear and nonlinear regression models to estimate operating costs. The nonlinear model includes transformation of predictor and response variables for correcting non-normality in the distribution of the data by application of the Box-Cox-Plot (Box and Cox, 1964). Therefore, an improvement of the model in terms of quality and performance is expected (Schmidt, 2009). Consequently, the term nonlinear does not indicate a nonlinear relationship between predictor and response variables.

In contrast to regression models, artificial neural network (ANN) models are able to represent nonlinear relationships between response and predictor variables. Inspired by the operation of the nervous system of humans and animals, ANNs are capable of learning and generalising from experience. They are considered as tools for construction since the 1990s (Moselhi, Hegazy, and Fazio, 1991) and are utilised for the estimation of construction costs in various studies.

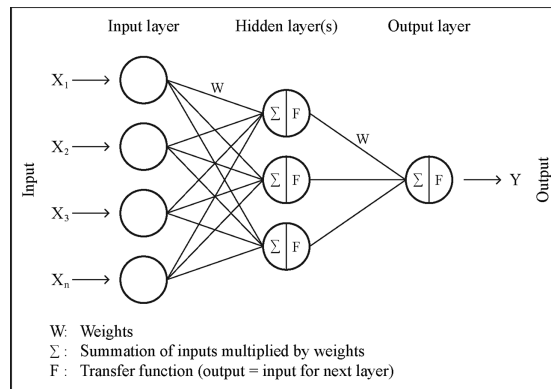


Figure 1: Typical architecture of a MLP neural network

For the estimation and identification of cause-effect relationships, the neural network architecture of multi-layer perceptrons (MLP) is most suitable (Backhaus et al., 2013) and therefore employed as a statistical method in the current study. MLPs typically consist of multiple layers of neurons as illustrated in Figure 1. Values of the predictor variables X_i are fed to neurons in the input layer, weighted and transferred to neurons of the first hidden layer. The inputs are summed up and then processed to the neurons of the next layer (or output layer) if the requirements of a transfer function are fulfilled. The output error is kept as small as possible by continuous comparison of the estimated and observed values and adjustment of the connection weights.

Based on the results of the regression and ANN models, cost indicators as a further method for the estimation of operating costs are developed and evaluated in the current study. Therefore, a suitable reference quantity is determined and cost indicators categorised according to identified predictor variables are presented.

The estimation quality and performance of the regression and ANN models can be determined by the accuracy of estimation compared to the underlying empirical data by the coefficient of determination R^2 as goodness-of-fit-index. The adjusted R^2 additionally takes the degree of freedom into account and consequently serves as a more reliable measure not depending on the number of predictor variables included in the model. Furthermore, the normalised root-mean-square error (CV)RMSE is used as an indicator to measure the standard deviation of the distance between observed and estimated values for evaluation of the statistical models.

The mean absolute percentage error (MAPE) is not only utilised as a measure of quality and performance to determine the goodness-of-fit of the statistical models, but also to measure the estimation performance under independent and unbiased conditions employing a test sample. The MAPE is defined as follows:

$$MAPE = \frac{1}{n} \sum_{i=1}^n \left| \frac{O_i - E_i}{O_i} \right| * 100\%$$

where O_i is the observed value, E_i is the estimated value, and n is the size of the sample.

To conduct statistical analysis based on empirical data, potential variables predicting the response variable have to be selected by the review of literature, by interviews, or by surveys (Fellow and Liu, 2008). Based on a selection by review of literature, a wide range of variables potentially influencing the operating costs (cf. Chapter 3) are considered for model development in the current study.

The response variable of the statistical models is defined as operating costs per year (Euro/a) according to German standard DIN 18960 (2008). Operating costs basically include supply of water, heating energy, electricity, disposal of water and waste, and costs for cleaning and care of indoor and outdoor facilities. Furthermore, costs for operation, inspection, and maintenance of

building structures and technical installations as well as costs for security, surveillance, and statutory charges are included.

3. Data sample

The empirical approach of the current study employs a data sample consisting of 206 occupied facilities. The data collection was conducted in the years 2008 until 2014 in Germany and includes data provided by 25 project partners. The data were complemented on-site the facilities, using a standardised questionnaire. Among operating cost data, the sample contains possible predictor variables, e.g. quantities, information about utilisation and location, and evaluations of the condition of building structures and technical installations.

Table 1: Available qualitative variables

Variable	Characteristic	No. obs.	Percentage ^[a]
Thermal mass	Heavy thermal mass	176	85.4%
	Light thermal mass	30	14.6%
Standard of building automation	High standard	82	39.8%
	Low standard	124	60.2%
Standard of technical installations	High standard	153	74.3%
	Low standard	53	25.7%
Cleaning services	External contractor	189	91.7%
	Internal cleaning services	17	8.3%
Type of heating energy source	District heating	70	34.0%
	Electricity	11	5.3%
	Gas	110	53.4%
	Oil	15	7.3%
Type of facility	Care retirement home	13	6.3%
	Church building	11	5.3%
	Community hall	5	2.4%
	Fire department	5	2.4%
	Kindergarten	102	49.5%
	Library	4	1.9%
	Municipal building	8	3.9%
	Research/teaching	10	4.9%
	School facility	22	10.7%
	Sport facility	19	9.2%
Town hall	7	3.4%	
Kitchen	Kitchen/canteen	115	55.8%
	Tea kitchen	35	17.0%
	None	56	27.2%

^[a] Total sample size is 206.

Potentially relevant qualitative variables are presented in Table 1 including their characteristics, their particular number of observations, and their percentage of the total sample. All available quantitative variables employed in the statistical investigation are described in Table 2. Operating costs as analysed response variable are adjusted to 2nd quarter 2015 prices including German VAT. Cost data were monitored over at least 1 up to 5 years, depending on the availability of data from the particular project partner. Cost indicators are created employing the gross external floor area (GEFA) defined by CEEC (2008) as reference quantity (cf. Chapter 4.1).

For an unbiased validation of the examined statistical methods, the total sample of 206 observations is divided into two subsamples. The training sample consists of 186 observations

(90% of the total sample) and serves as a basis for the development of the statistical models and cost indicators. The test sample includes 20 observations (10% of the total sample) and is used to measure the estimation performance of the developed models and cost indicators. The test sample is selected randomly and shall be representative of the training sample.

Table 2: Available quantitative variables

Variable	Type ^[a]	Mean	Standard deviation	Min.	Lower quartile	Median	Upper quartile	Max.
Absolute operating costs (Euro/a)[b]	RE	97,481	124,719	7,000	20,288	44,419	126,546	702,644
Operating cost indicators (Euro/m ² GEFA*a)[b]	RE	39.13	15.21	10.21	28.37	37.81	47.78	79.76
Gross external floor area GEFA (m ²)	CN	2,873	3,774	160	578	1,276	3,438	22,272
Share of usable floor area UFA on GEFA (%)	CN	0.54	0.12	0.25	0.46	0.54	0.62	0.81
Share of heatable GEFA (%)	CN	0.88	0.12	0.39	0.82	0.91	0.96	1.00
Share of ventilated and air-conditioned GEFA (%)	CN	0.09	0.15	0.00	0.00	0.02	0.12	0.76
Share of regularly cleaned usable floor area UFA (%)	CN	0.78	0.13	0.21	0.72	0.83	0.88	0.94
Share of sanitary area on GEFA (%)	CN	0.05	0.03	0.00	0.03	0.05	0.06	0.17
Average floor size (m ²)	CN	695	628	87	292	496	878	3,954
Average storey height (m)	CN	3.95	1.50	2.50	3.10	3.50	4.26	14.08
Number of floors	DN	3.52	2.22	1	2	3	5	14
Number of elevator stops	DN	1.23	2.16	0	0	0	2	12
Number of sanitary facilities	DN	8.66	14.98	0	2	4	8	122
Share of glass surfaces on above-grade exterior walls (%)	CN	0.27	0.12	0.06	0.18	0.26	0.34	0.62
Share of double or triple glazing on ext. glass surfaces (%)	CN	0.91	0.27	0.00	1.00	1.00	1.00	1.00
Share of defective building construction (%)	CN	0.14	0.14	0.00	0.03	0.11	0.19	0.81
Share of defective technical installations (%)	CN	0.12	0.15	0.00	0.00	0.06	0.17	0.77

Number of observations for all quantitative predictor variables: 206.

^[a] RE stands for response variables, CN stands for continuous numeric variables and DN stands for discrete numeric variables.

^[b] Costs and cost indicators are adjusted to 2nd quarter 2015 prices including VAT.

4. Statistical investigation

4.1 Model development

Based on the pre-analysis presented in Chapter 3, statistical models are stepwise developed employing a training sample of 186 observations. Describing the causal interrelations between the response and the predictor variables, the main objective of the models is set to be the estimation of operating costs. Besides a linear regression model, a nonlinear regression model with transformed variables for the correction of non-normality of the underlying data is presented. Furthermore, an artificial neural network (ANN) model is developed. The models are summarised in Table 3 including measures of quality and performance.

Table 3: Comparison of relevant statistical models for estimation of operating costs

Model	No. variables	R ²	R ² (adj.)	MAPE	CV(RMSE)	Outliers	No. obs
Response variable: Operating cost indicators (Euro/m ² GEFA*a)							
OP ₁ Linear regression model	5	63.2%	59.7%	20.4%	23.8%	9 (4.8%)	186
OP ₂ Nonlinear regression model	7	77.3%	74.9%	16.5%	21.4%	6 (3.2%)	186
OP ₃ Artificial neural network (MLP)	7	*	70.3%	16.8%	21.6%	12 (6.5%)	186

It can be assumed that the estimation of cost indicators has more practical relevance for a variety of reasons, e.g. the comparability of indicators for benchmarking or long-term monitoring of performance. Based on the evaluation of models estimating absolute costs and cost indicators, the gross external floor area (GEFA) is identified as most suitable reference

quantity. Therefore, only models estimating operating cost indicators (Euro/m² GEFA*a) are presented in the current study. Comparing the developed models, the nonlinear regression model OP₂ offers the best quality and performance in terms of accuracy with a R² of 77.3% and an adjusted R² of 74.9%. Furthermore, the MAPE of model OP₂ indicates the best accuracy with the lowest value of 16.5% compared with nonlinear regression model OP₁ and ANN model OP₃.

4.2 Specifications and parameters of the best-fitting model

As presented in Chapter 4.1, various statistical models for the estimation of operating cost indicators are developed. In the current chapter, the best-fitting nonlinear regression model OP₂ is specified and relevant parameters are presented in detail. Table 4 gives a description of the included predictor variables and their coefficients.

Table 4: Description of coefficients for nonlinear regression model OP₂

Response variable (Y)	Transf. (λ)	R ²	R ² (adj.)	MAPE	CV(RMSE)	p-value	No. obs.
Operating cost indicators (Euro/m ² GEFA*a)	0 (LN)	77.3%	74.9%	16.5%	21.4%	0.000	186
Predictor variable (X)	Transf. (λ)	Coefficient (β)	Coefficient Std. Error	Standardised Coefficient	t-value	p-value	VIF
β ₀ Constant	*	3.995	0.245	0.000	16.33	0.000	*
X ₁ Share of heatable GEFA (%)	2 (SQ)	0.586	0.116	0.260	5.05	0.000	1.93
X ₂ Share of regularly cleaned UFA (%)	2 (SQ)	0.521	0.136	0.217	3.84	0.000	2.42
X ₃ Average floor size (m ²)	0 (LN)	-0.125	0.031	-0.219	-4.03	0.000	2.19
X ₄ Share of defective tech. installations (%)	0.5 (SQR)	0.239	0.080	0.121	2.97	0.003	1.25
X ₅ Cleaning services	*	*	*	0.332	*	0.000	*
<i>External contractor</i>	*	0.000	0.000	*	*	*	*
<i>Internal cleaning services</i>	*	-0.517	0.063	*	-8.16	0.000	1.22
X ₆ Type of heating energy source	*	*	*	0.175	*	0.000	*
<i>District heating</i>	*	0.000	0.000	*	*	*	*
<i>Electricity</i>	*	0.238	0.083	*	2.85	0.005	1.31
<i>Gas</i>	*	0.124	0.042	*	2.98	0.003	1.78
<i>Oil</i>	*	-0.037	0.072	*	-0.51	0.609	1.56
X ₇ Type of facility	*	*	*	0.539	*	0.000	*
<i>Care retirement home</i>	*	0.000	0.000	*	*	*	*
<i>Church building</i>	*	-1.189	0.108	*	-11.03	0.000	2.42
<i>Community hall</i>	*	-1.015	0.124	*	-8.20	0.000	1.65
<i>Fire department</i>	*	-0.683	0.129	*	-5.31	0.000	1.77
<i>Kindergarten</i>	*	-0.474	0.082	*	-5.80	0.000	4.73
<i>Library</i>	*	-0.717	0.129	*	-5.55	0.000	1.44
<i>Municipal building</i>	*	-0.654	0.112	*	-5.84	0.000	1.86
<i>Research/teaching</i>	*	-0.534	0.105	*	-5.08	0.000	2.09
<i>School facility</i>	*	-0.507	0.093	*	-5.46	0.000	3.24
<i>Sport facility</i>	*	-0.438	0.093	*	-4.69	0.000	2.96
<i>Town hall</i>	*	-0.477	0.115	*	-4.14	0.000	1.70

Following equation describes the nonlinear regression model OP₂:

$$Y = e^{\beta_0} * e^{\beta_1 X_1^2} * e^{\beta_2 X_2^2} * \chi_3^{\beta_3} * e^{\beta_4 \sqrt{X_4}} * e^{\beta_5 X_5} * e^{\beta_6 X_6} * e^{\beta_7 X_7}$$

Transformations of both response and predictor variables are presented with their respective lambda (λ) as determined by Box-Cox transformation. The coefficients (β) for the regressions constant and variables are complemented by the standard error displaying the standard deviation of the coefficient's estimate for the sample. The standardised coefficients indicate the effect of the predictors even if they are measured on different scales. The standardised coefficients for

categorical predictor variables are determined by re-calculating the regression including composite variables as established by Eisinga, Scheepers, and van Snippenburg (1991).

According to the t-values exceeding a value of 1.972 (significance level alpha set to 0.05), a generalised significance is indicated for all predictor variables included in model OP_2 . The 4 quantitative and 3 qualitative variables are tested on their empirical significance complying with the threshold of the p-value on an α -level of 0.05. Since the present study is not conducted on an experimental level where variables can be observed isolated, multi-collinearity of the predictor variables exists to an extent (Chatterjee and Hadi, 2006). Nonetheless, values of the variance inflation factor VIF fall below the determined threshold of 5 for all predictor variables.

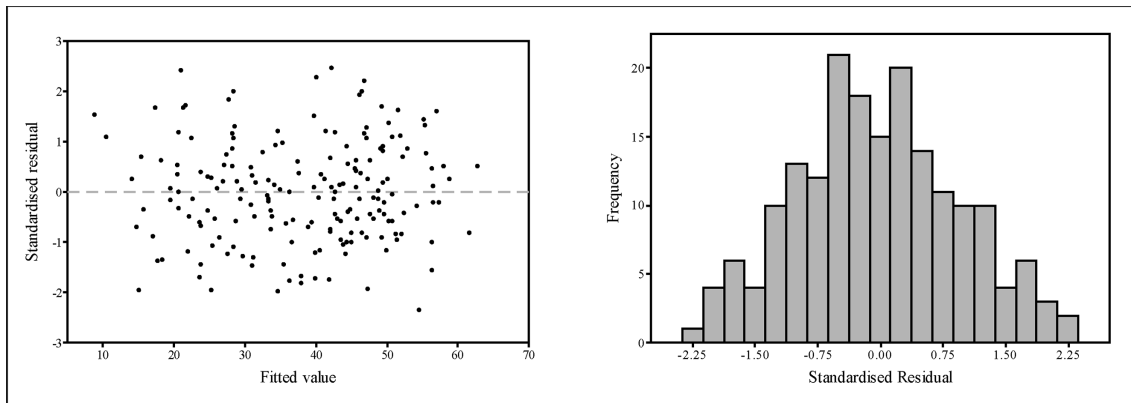


Figure 2: Residuals versus fitted values and histogram of residuals for model OP_2

As illustrated in the scatterplot and histogram in Figure 2, the variance of the residuals (difference between observed and estimated values) appears to be independent, randomly scattered, and heteroscedastic. Therefore, a correctly specified regression model OP_2 with no missing terms, extreme outliers, or influential points is indicated.

4.3 Cost indicators

The statistical methods compared in the current study include the estimation of operating costs employing cost indicators. As specified in Chapter 4.1, the best results in terms of quality and performance can be achieved for models including the gross external floor area GEFA. Therefore, the GEFA is determined as reference quantity for the generated cost indicators (Euro/m² GEFA*a). According to the standardised coefficient, the type of facility is identified as predictor variable with the greatest effect on operating costs in nonlinear regression model OP_2 (cf. Table 4). Based on the training sample including 186 observations, cost indicators with a categorical distinction according to the type of facility are presented in Table 5. In addition, corresponding boxplots are illustrated in the Appendix of the current study.

Table 5: Utility supply cost indicators

Type of facility	Lower quartile ^[a]	Median ^[a]	Upper quartile ^[a]	No. obs.
Care retirement home	30.11	45.64	67.48	12
Church building	12.56	14.49	19.93	10
Community hall	16.07	20.86	22.86	5
Fire department	15.27	22.07	34.14	5
Kindergarten	35.6	43.37	54.03	92
Library	22.23	27.80	30.85	4
Municipal building	21.02	26.39	31.16	7
Research/teaching	22.76	27.80	38.38	9
School facility	29.66	33.74	35.31	19
Sport facility	38.81	42.44	49.04	17
Town hall	25.01	26.28	32.69	6

^[a] Operating cost indicators (Euro/m² GEFA*a), costs are adjusted to 2nd quarter 2015 prices including VAT.

4.4 Evaluation of performance and quality

The validation of the statistical methods is performed employing a test sample of 20 observations not included in the development of the statistical models and cost indicators. Therefore, unbiased and independent inferences about the estimation accuracy are expected. Observed and estimated values for the statistical models and the estimation by cost indicators are presented in Table 6. The estimated values are calculated by applying the observed predictor variables into the models (OP₁, OP₂, and OP₃) or selected according to the respective type of facility (indicators).

Table 6: Comparison of observed and estimated values for the test sample

No.	Type of facility	Obs. ^[a]	Linear regr. (OP ₁)		Nonlin. Regr. (OP ₂)		ANN (OP ₃)		Indicators (Median)		Pref.
			Est. ^[a]	APE ^[b]	Est. ^[a]	APE ^[b]	Est. ^[a]	APE ^[b]	Est. ^[a]	APE ^[b]	
4	Sport facility	45.20	44.23	2.1%	50.14	10.9%	47.35	4.7%	42.44	6.1%	Lin.
7	School facility	38.95	42.15	8.2%	37.45	3.8%	34.06	12.5%	33.74	13.4%	Nonl.
17	School facility	38.43	34.92	9.1%	38.72	0.7%	37.89	1.4%	33.74	12.2%	Nonl.
57	Kindergarten	77.50	56.95	26.5%	53.77	30.6%	65.41	15.6%	43.37	44.0%	ANN
59	Research/teaching	29.47	33.17	12.6%	28.40	3.6%	28.25	4.1%	27.80	5.7%	Nonl.
65	Kindergarten	45.68	46.03	0.8%	41.80	8.5%	44.66	2.2%	43.37	5.1%	Lin.
88	Kindergarten	42.34	42.26	0.2%	46.65	10.2%	36.14	14.7%	43.37	2.4%	Lin.
94	Church building	27.03	23.08	14.6%	22.36	17.3%	28.47	5.3%	14.49	46.4%	ANN
97	Kindergarten	69.67	50.29	27.8%	51.80	25.7%	53.97	22.5%	43.37	37.8%	ANN
115	Kindergarten	47.52	42.74	10.1%	43.36	8.8%	41.28	13.1%	43.37	8.7%	Ind.
122	Care retirem. home	28.84	37.32	29.4%	35.08	21.6%	35.59	23.4%	45.64	58.3%	Nonl.
123	Municipal building	36.60	29.43	19.6%	27.09	26.0%	31.63	13.6%	26.39	27.9%	ANN
133	Kindergarten	65.34	51.19	21.6%	56.10	14.1%	55.55	15.0%	43.37	33.6%	Nonl.
149	Kindergarten	16.88	25.30	49.9%	23.98	42.1%	27.43	62.5%	43.37	56.9%	Nonl.
161	Kindergarten	43.17	49.16	13.9%	48.35	12.0%	52.13	20.7%	43.37	0.5%	Ind.
168	Town hall	45.85	39.87	13.0%	42.15	8.1%	38.86	15.2%	26.28	42.7%	Nonl.
170	Sport facility	32.99	28.22	14.5%	26.57	19.5%	27.90	15.5%	42.44	28.6%	Lin.
189	Kindergarten	38.47	44.97	16.9%	38.78	0.8%	37.20	3.3%	43.37	12.7%	Nonl.
193	Kindergarten	35.21	46.80	32.9%	42.99	22.1%	45.97	30.5%	43.37	23.2%	Nonl.
203	School facility	31.68	39.85	25.8%	38.30	20.9%	42.97	35.6%	33.74	6.5%	Ind.
Total (MAPE)			17.5%		15.4%		16.6%		28.6%		

^[a] Observed and estimated values: Operating cost indicators (Euro/m² GEFA*a), costs are adjusted to 2nd quarter 2015 prices including VAT.

^[b] Absolute percentage error.

The absolute percentage error (APE) quantifies the accuracy of the estimated values for all 20 observations of the test sample. Furthermore, the preference for a statistical method according to the estimation accuracy is presented. With a preference of 9 out of 20 observations, values of

the APE ranging between 0.7% and 42.1%, and a mean absolute percentage error (MAPE) of 15.4%, the most accurate estimation is indicated for nonlinear regression model OP₂.

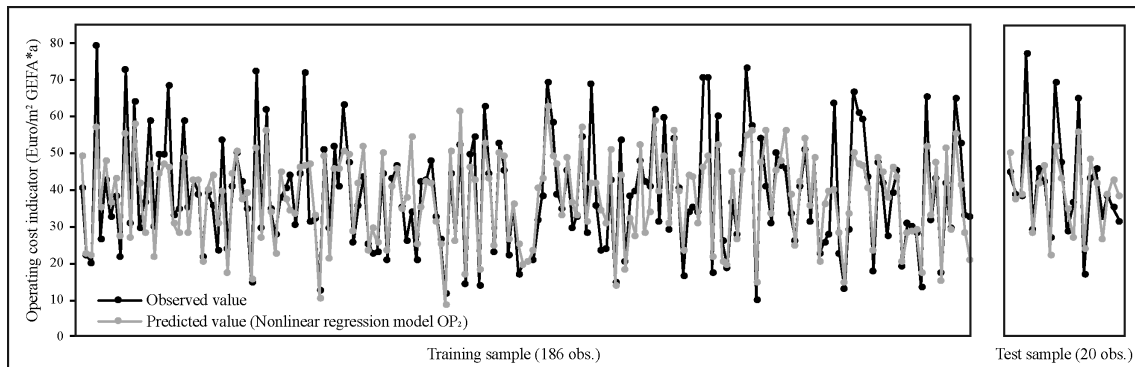


Figure 3: Comparison of observed values and values estimated by model OP₂

A comparison of the observed values and the values estimated by nonlinear regression model OP₂ is illustrated for both training sample and test sample in Figure 3. The graph reveals relatively consistent and small residuals for both training and test samples and indicates a good estimation accuracy for the statistical model.

5. Results and discussion

Comparing statistical methods for the estimation of operating costs employing an independent and representative test sample of 20 observations, a mean absolute percentage error (MAPE) of between 15.4% and 28.6% can be achieved as summarised in Table 7. The adjusted R² of the developed linear and nonlinear regression and artificial neural network models ranges between 74.9% and 59.7% with a CV(RMSE) of between 21.4% and 23.8%. The most accurate estimation of operating costs is provided by the nonlinear regression model OP₂ employing the gross external floor area GEFA as reference quantity. The model offers an adjusted R² of 74.9%, a CV(RMSE) of 21.4% and a MAPE of 16.5% (training sample) and 15.4% (test sample).

Table 7: Summary of statistical methods estimating operating costs

Sample	Linear regression (OP ₁)		Nonlin. regression (OP ₂)		ANN (OP ₃)		Indicators (Median)		No. obs.
	R ² (adj.)	CV(RMSE)	R ² (adj.)	CV(RMSE)	R ² (adj.)	CV(RMSE)	R ² (adj.)	CV(RMSE)	
Training sample	59.7%	23.8%	74.9%	21.4%	70.3%	21.6%	*	*	186
	MAPE	No. pref.	MAPE	No. pref.	MAPE	No. pref.	MAPE	No. pref.	No. obs.
Training sample	20.4%	27 (14.5%)	16.5%	81 (43.5%)	16.8%	42 (22.6%)	25.3%	33 (17.7%)	186
Test sample	17.5%	4 (20.0%)	15.4%	9 (45.0%)	16.6%	4 (20.0%)	28.6%	3 (15.0%)	20
Total	20.1%	31 (15.0%)	16.4%	90 (43.7%)	16.8%	46 (22.3%)	25.6%	36 (17.5%)	206

With a significance level of alpha (α) determined as 0.05 for the current study, 7 significant predictor variables influencing operating cost indicators are identified for model OP₂ (ordered descending by the size of effect determined by the standardised coefficient of the regression):

- Type of facility
- Cleaning services

- Share of heatable gross external floor area
- Average floor size
- Share of regularly cleaned usable floor area
- Type of heating energy source
- Share of defective technical installations

The developed statistical models show better results in terms of accuracy comparing them to cost indicators employed for the estimation of operating costs. Due to a relatively small data sample, cost indicators with a categorical distinction according to only one predictor variable can be presented and evaluated. Therefore, the accuracy of the estimation by the regression and ANN models including between 5 and 7 significant predictor variables is expected to be more accurate. The correction of existent non-normality in the distribution of the data results in a better performance of the nonlinear regression model compared with the linear model. Though the nonlinear regression model performs slightly better, nonlinear relationships between the response variable and the predictor variables are indicated by the results achieved by the ANN model.

6. Conclusion

The current study examines multiple statistical methods for the estimation of operating costs on the basis of a data sample of 206 occupied facilities. Therefore, linear and nonlinear regression models and artificial neural network models are developed, specified, and evaluated in terms of their estimation accuracy. Significant variables influencing the operating costs are identified and presented. Based on the results of the developed statistical models, categorised cost indicators for the estimation of operating costs are introduced. All statistical methods are evaluated for their performance and quality employing an independent and randomly selected test sample.

The results show the best estimation accuracy for the nonlinear regression model and the artificial neural network model. The minor differences of the measures of performance and quality for both models utilising the same predictor variables indicate correctly specified models. The procedures of model development and the evaluation of the results are presented in detail and may serve as a basis for further research on the estimation of operating costs and the identification of significant predictor variables.

Future research may improve its results considering the limitations of the current study. Due to a limited number of observations of some types of facilities, the accuracy of the presented statistical methods could be improved by extension of the data sample. Moreover, future approaches may consider further types of facilities for the development of cost estimation methods (e.g. health service facilities, industrial facilities, laboratories). The data sample employed in the current study includes solely properties owned and operated by public-sector institutions. For the identification of the influence of strategies on operating costs (e.g. energy contracting, outsourcing, public-private partnership, maintenance strategies), further research may include data from properties owned and operated by private institutions.

Though operating costs represent a substantial amount of the life-cycle costs of facilities, further approaches may extend their focus on cost types such as the maintenance and the repair of facilities. Likewise, the implementation of additional statistical methods for the estimation of costs may be considered and evaluated (e.g. decision tree analysis). Ultimate objective should be the development of standardised cost models and applicable tools for the holistic estimation of life-cycle costs of facilities including planning, construction, operation, maintenance, repair, and reuse or demolition.

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Appendix

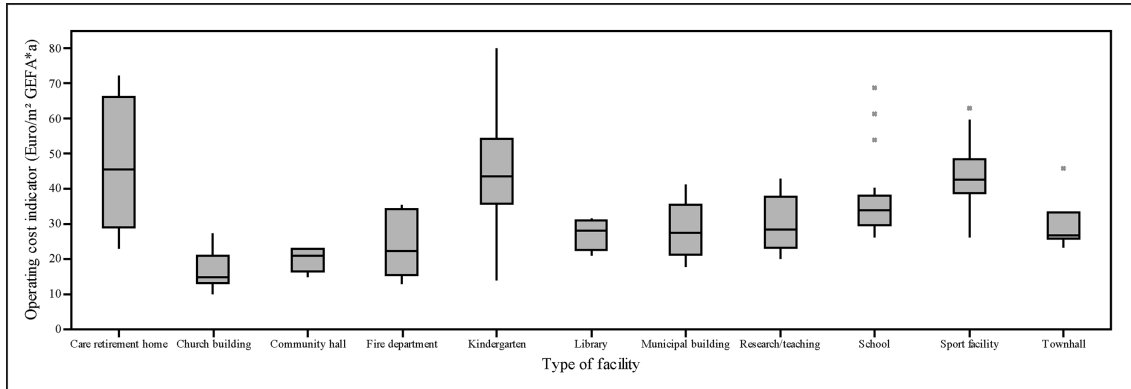


Figure A1: Boxplots of operating cost indicators categorised according to the type of facility

DEVELOPING BUDGET REFERENCE SYSTEMS: TWO CASE STUDIES

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Abstract

This paper presents two case studies about developing budget reference systems. One of them was created to support contractors decisions related to construction costs in a private company. The other one is an ongoing job where "Caixa Econômica Federal", the main public institution dealing with financial support to construction in Brazil, intends to improve its skills to estimate construction costs. In order to improve managers demands, this paper shows how to develop a reference system, based on data site collection and analysis. This empirical procedure gives more confidence to the proposed figures.

Keywords: Budget, productivity, construction costs

1. Introduction

Construction cost estimation is always an important theme to be discussed. Contractors and public and private developers often debate about the correct value to be addressed to a specific project (BAKHSI; TOURAN, 2014; LAI et al, 2008; OZTAS; OKMEN, 2003; SHEHU et al, 2014; WILMOT; CHENG, 2003). Cost understanding allows several managers decisions: from the project's viability to the cost control during the building production (JIBOURI, 2003). But it is very accepted that construction costs may vary in a large range accordingly to several features of the project being produced (CHENG, 2014; MAHAMID, 2013; POLAT et al, 2014; WILLIAMS; GONG, 2014).

In order to help decisions based on cost understanding, estimates reference systems are available to support cost estimation. Private and public companies dealing with construction base their cost estimation on a process that uses Cost Data Books. In this context it is important these books contain widespread and reliable information.

In Brazil exists a public database of cost construction which is a reference to finance several kinds of building construction by the Brazilian Government. It's called National System of Costs Survey and Indexes of Construction (SINAPI), which is indicated in the Brazilian Law. The system is maintained by the Brazilian government's financing agent Caixa Econômica Federal. The SINAPI is being updating by a pool of universities in order to represent the different used construction all over the country, as well to comprehend new technologies not contemplated in the previous versions.

Based on author's previous research experiences, this paper presents both guidelines for the development and some parts of two cost estimation systems developed by them recently for a private and a public companies.

2. Cost construction reference system

Cost estimation can be discussed under several points of view including: monetary versus physical resources approach; global versus partial costs; type of project; contents and context of a project; developer versus contractor; etc.

Based on the literature, the authors see the process of estimating the building construction cost, in terms of direct costs¹, as composed by the following steps (Figure 1): 1) the breakdown of the final product into smaller parts; 2) the quantity estimation of each part (surveying); 3) the

¹ DIRECT COSTS – “Costs of completing work that are directly attributable to its performance and are necessary for its completion. 1) In construction, the cost of installed equipment, material, labor and supervision directly or immediately involved in the physical construction of the permanent facility. 2) In manufacturing, service, and other non-construction industries: the portion of operating costs that is readily assignable to a specific product or process area”. (AACE; 2015)

forecast of the effort (in terms of the items labor, material and equipment) associated to one unit for each part of the product; 4) the evaluation of unit costs for each item; 5) defining global cost.

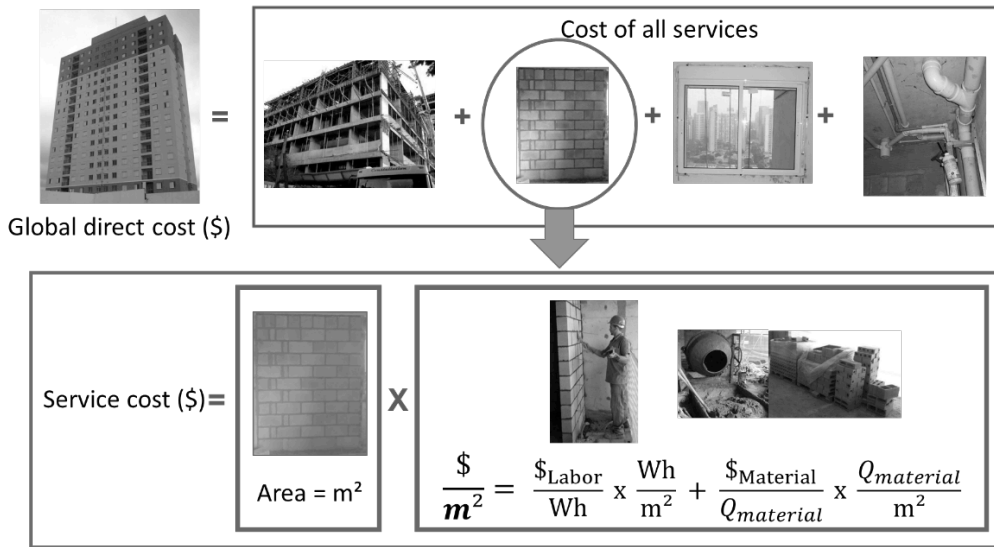


Figure 1: – Estimating building construction cost (*Wh* = workhours, *Q material* = quantify of materials)

2.1 Product breaking down

Several approaches are presented in the literature to help divide the whole product into smaller parts (ISO TR 14177:1994; ISO/ DIS 12006-2, 1998; RS Means, 2008; Cho et all , 2013). This paper considers the approach suggested by Marchiori (2009) as the direction to be followed. Breakdown (Figures 2 and 3) is based both on the division for the product but also in terms of the process to be adopted.

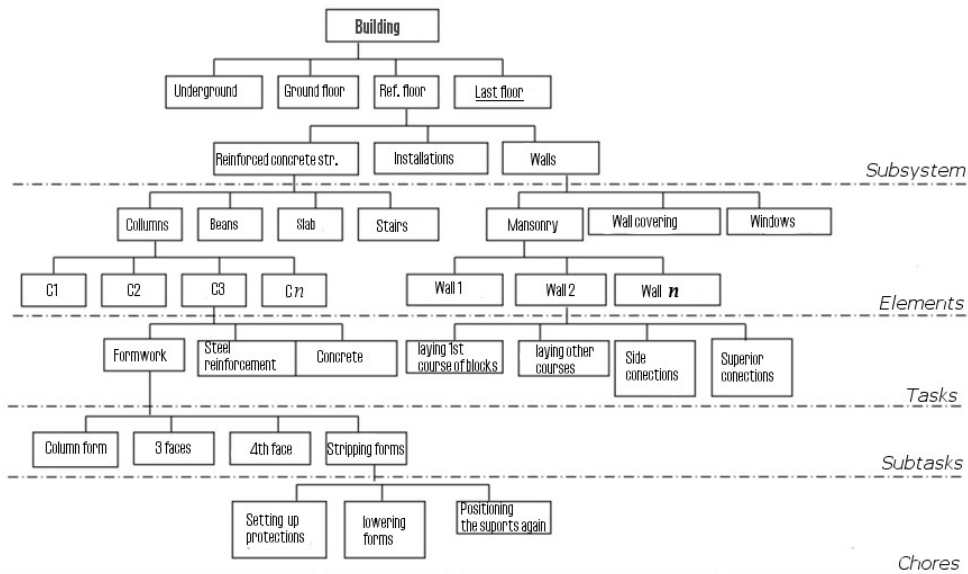


Figure 2: Division of the product (Marchiori, 2009)

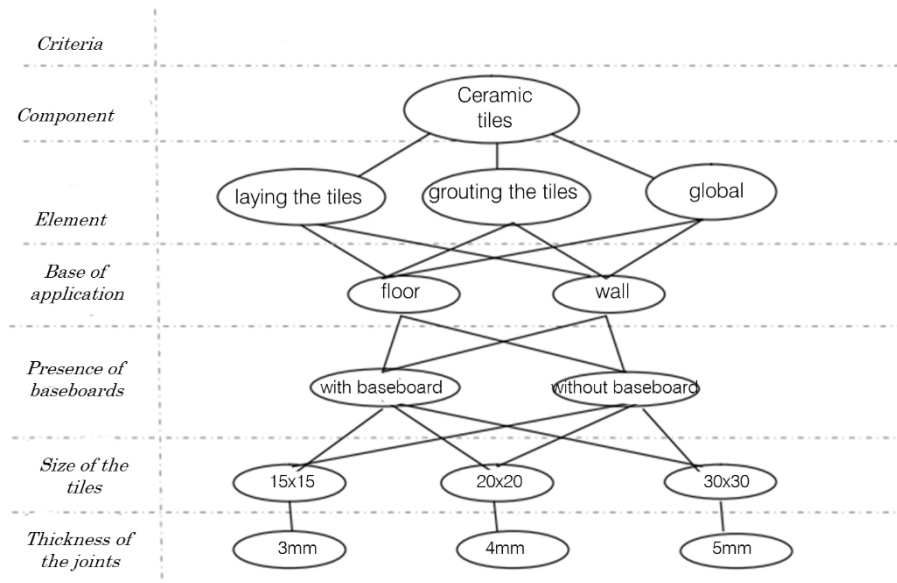


Figure 3: Division in terms of the process (Marchiori, 2009)

The structure proposed by Marchiori (2009) represents better the found conditions in the building sites than the previous structure of information in the Brazilian construction cost databases, once it contemplates what is being done, by who and where, allowing to use of this structure for the integration of information systems, for example to control costs and time in the level of detail that anyone wants to analyze. This structure was used in both case studies.

2.2 Surveying

Once the “parts” are defined, one has to measure each part extension. Two different approaches are normally found in the literature: measuring the effective extension (BANSAL; PAL, 2007; JADID; IDREES, 2007; SHEN, ISSA 2010) versus take into consideration specificities of the product to define “equivalent” amounts to be produced. See Figure 4 as an example of the two alternatives.

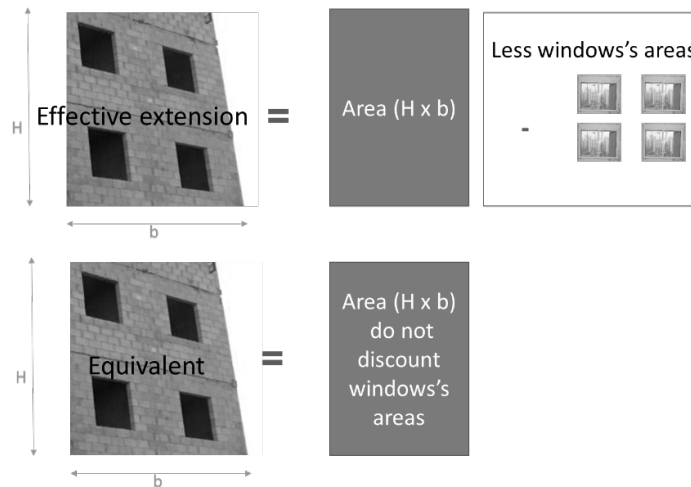


Figure 4: Measuring blockwork.

The authors consider the effective amount of a job has to be considered in order to avoid mistakes in defining what is quantity and relative difficulty.

2.3 Unit Efforts

Different approaches can be used to express the needed “efforts” to produce an amount of certain product. For example, RSMMeans define a team with equipments and indicates the job quantity this team makes in one hour (see Figure 5 as an example of RSMMeans approach).

22 11 Facility Water Distribution					
22 11 13.74 - Facility Water Distribution Piping					
22 11 13.75 Pipe, Plastic					
		Crew	Daily Outputs	Labor-Hours	Unit
1930	3" diameter	Q1	53	0,302	L.F.
Crew Q-1					
1 Plumber					
1 Plumber Apprentice					

Figure 5: Unit demands accordingly to RSMMeans (2008)

The authors consider the most appropriate way to define effort associated to a product production is expressing the amount of each resource demanded to produce 1 unit of the addressed product. Figure 6 show an example accordingly to TCPO.

Plumbing installations			
Plumbing - PVC pipe			
13.007.000096.SER PVC pipe for adhesive jointing ø 75 mm - unit			
Code	Components	Unit	Average Consumption
01.001.000005.MOD	Plumber Apprentice	h	0,406
01.001.000001.MOD	Plumber	h	0,406
14.001.000471.MAT	Cleaning solution for PVC	l	0,001
14.001.000511.MAT	Brown PVC pipe for adhesive jointing (75 mm diameter)	m	1,05
14.001.000564.MAT	jointing adhesive for PVC	kg	0,002

Figure 6: Unit demands accordingly to TCPO (2014)

Unit efforts can be seen as the efficiency in processing the resources. As far as the demanded resources are labor, materials and equipment, the estimator has to deal respectively with labor productivity, material consumption and equipment efficiency.

This paper considers efficiency rates should be defined based on the Factor Model approach (see Thomas et al (1990) for additional information). Figure 7 shows the indicator to be used in a budget is calculated adding a potential unit rate (pUR) to a value considering the usual lack of efficiency (dUR). Both pUR and dUR can be defined based on the statistical analysis of a real database collected in projects of the company defining its budget reference system.

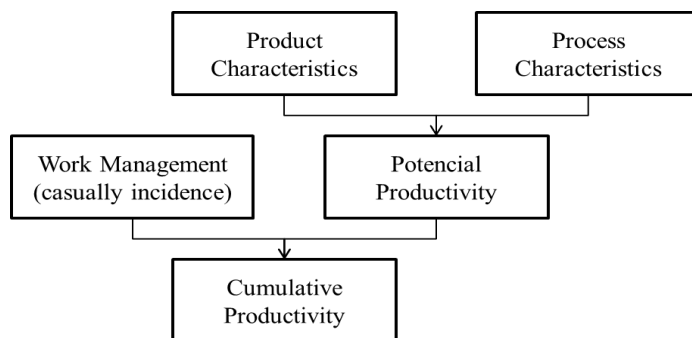


Figure 7: Factor Model as basis to define efficiency unit rates (SOUZA et al, 2014)

2.4 Unit Costs Definition

Each resource has to be evaluated in terms of its cost. The process of evaluating unit costs can also follow several directions. It can be based on price lists, available in specialized magazines, or it can result from a unit cost search.

Both in contractors and in developers many times one can find a department responsible by collecting local prices to support local projects cost estimation. It is also usual to consider the minimum value coming from the search to be adopted to compose the budget.

Once the reference system has to be used in a larger area (for example a country), unit prices can vary accordingly to regional features. In this case, search have to take into account this variability; the subareas to be represented can be larger or smaller as a function of the reliability to be given to the reference system.

2.5 Global Cost

Once the product is divided into parts, each part is measured, unit resources demand is adopted and unit prices are considered, global direct cost is easily determined (accordingly to Figure 1 previously described).

3. Proposed Budget Reference Systems

This item describes some parts of two budget reference systems the authors have the opportunity to help improve. One of it belongs to a private multi story building developer; and the other is still being improved for the largest public funding company in Brazil.

3.1 Case Studies

3.1.1 Private multi story building developer (company A)

Company A is a large Brazilian construction company that works both with developing and producing its projects. Built area in 2015 was more than 16 million m². The goal was to improve building structures cost estimation for multi story buildings in the São Paulo city area.

3.1.2 Public funding (company B)

Financial institution that is the largest public bank in Latin America. This institution operates the application of funds from the Brazilian Federal Budget and operates in the financing of public and private works, mainly focused on basic sanitation, infrastructure and housing (OLIVEIRA et al, 2015).

This bank is also the sponsor of SINAPI – National System of Costs Survey and Indexes of Construction. According to the decree 7.983/2013, directs costs of a public construction must be based on the service compositions of an official system, as the SINAPI (OLIVEIRA et al, 2015).

This System, created in 1969, is the main source of free public construction costs in the country. Every month, the SINAPI web publishes costs references for housing, infrastructure and sanitation works carried out in an urban environment for the Brazil's 27 state capitals (OLIVEIRA et al, 2015).

The goal is to improve the existing budget reference system, dealing with more than 5.000 resources unit rates table providing support to better define unit costs.

3.2 Adopted Approach

In both cases the goal was to define unit rates for each resource demanded for a certain construction part. In order to get to these indicators, real values were collect in the field.

For company A, the number of case studies for each part was the case studies available at that moment. Due to the high number of ongoing contracts, the sample was ever bigger than B. For company B it was defined a minimum sample sample of 10 construction sites for any study.

Based on the collected data, the authors processed and analysed than in order to define the unit rate values. For company A, the results were expressed as a range of values associated to the reasons for better or worse performances. For company B, an unique value is associated to specific job description due to the public use of the figures. Figure 8 shows the main steps in developing the reference systems.

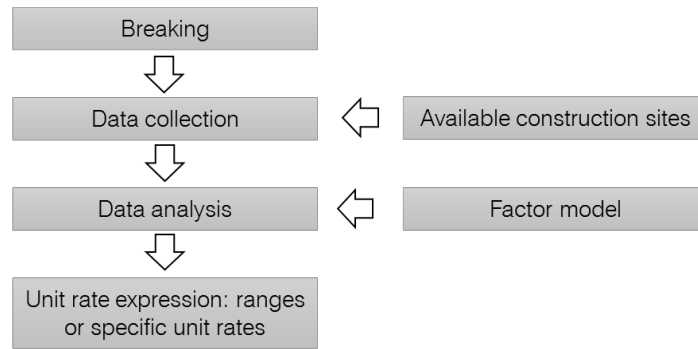


Figure 8: Main steps in developing the reference systems

One usual question is about how to take into account the job quality. It is important to state that data collection is related just to the production in accordance to the public and private standards.

3.3 Results

Here some relevant points are present, and not the complete performed job.

3.3.1 Company A

Concrete reinforced structure is one of the most important systems composing the multistory buildings of company A. Then, it was important to improve cost estimation for it. Once the structure conception vary significantly from one building to another, one of the most strong innovation in this reference system was to use the concept of variable productivity.

Figure 9 shows the process to define labor unit rate for column formwork. One can see the labor productivity can vary 90% from the easiest to the hardest conditions to produce one square meter of formwork.

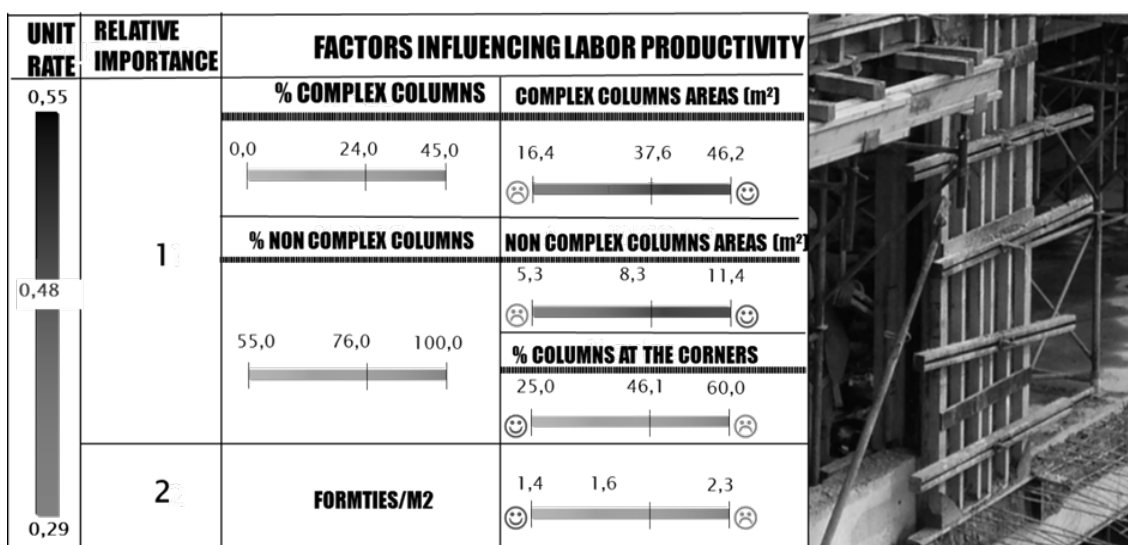


Figure 9: Results of Company A: Labor unit rate for column formwork

3.3.2 Company B

This still ongoing research job is being produced by a team with about 60 people and includes site data collection in 11 cities representing 3 areas of Brazil (see Figure 10)

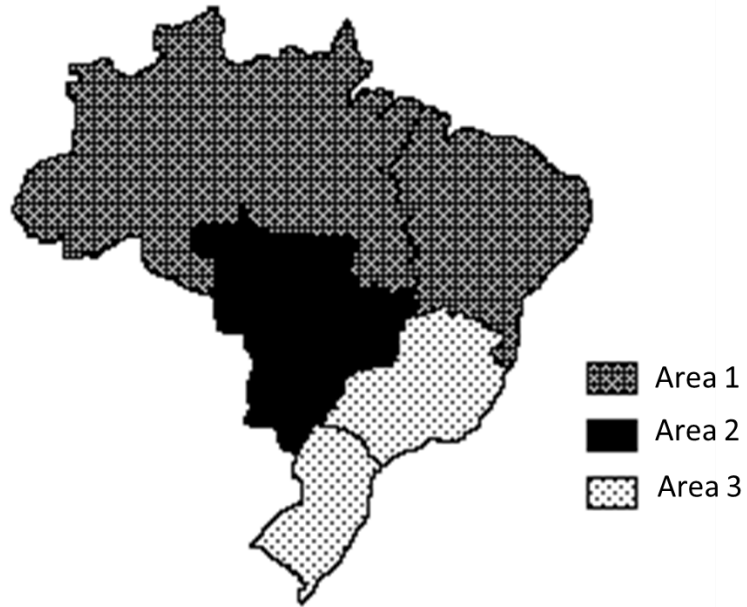


Figure 10: Represented areas in Brazil

Figure 11 shows an example of adopted “product breakdown” for one part of the building (screed). Notice that instead of having just one resources unit rates table for the job, figure 11 shows an extense bunch of alternatives to represent it.

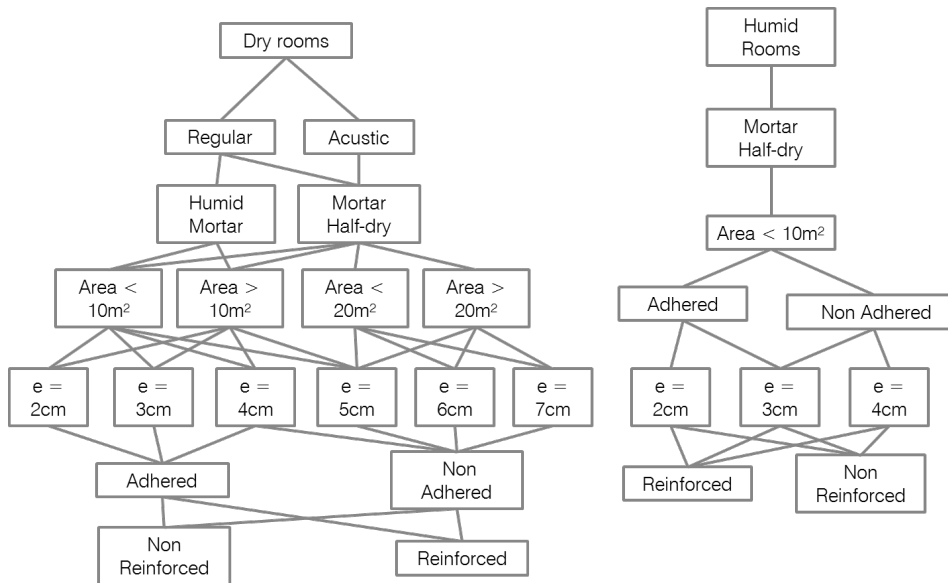


Figure 11: Breakdown of screed

Table 1 summarizes resources unit rates table defined to represent the same job. Here, instead of defining ranges of variation for each resource, a group of resources unit rates table tries to represent all the different features one can face to perform the job. Notice the labor unit rates described varies 200%; and the materials unit consumption includes losses that vary from 0,031 m³/m² to 0,076 m³/m².

Table 1: Breakdown of screed

nº	Local	Area	Type	Adhered	thickness (cm)	Reinforced	laborers (h/m ²)	Helpers (h/m ²)	Mortar (m ³ /m ²)
1	Dry rooms	Area < 10 m ²	Regular	Yes	2,00	Yes	0,32	0,16	0,0310
2	Dry rooms	Area < 10 m ²	Regular	Yes	2,00	No	0,29	0,15	0,0310
3	Dry rooms	Area < 10 m ²	Regular	Yes	3,00	Yes	0,35	0,18	0,0431
4	Dry rooms	Area < 10 m ²	Regular	Yes	3,00	No	0,33	0,16	0,0431
5	Dry rooms	Area < 10 m ²	Regular	Yes	4,00	Yes	0,38	0,19	0,0530
6	Dry rooms	Area < 10 m ²	Regular	Yes	4,00	No	0,36	0,18	0,0530
7	Dry rooms	Area > 10 m ²	Regular	Yes	2,00	Yes	0,27	0,13	0,0310
8	Dry rooms	Area > 10 m ²	Regular	Yes	2,00	No	0,24	0,12	0,0310
9	Dry rooms	Area > 10 m ²	Regular	Yes	3,00	Yes	0,30	0,15	0,0431
10	Dry rooms	Area > 10 m ²	Regular	Yes	3,00	No	0,27	0,14	0,0431
11	Dry rooms	Area > 10 m ²	Regular	Yes	4,00	Yes	0,33	0,17	0,0530
12	Dry rooms	Area > 10 m ²	Regular	Yes	4,00	No	0,30	0,15	0,0530
13	Dry rooms	Area < 10 m ²	Regular	No	4,00	Yes	0,32	0,16	0,0530
14	Dry rooms	Area < 10 m ²	Regular	No	4,00	No	0,29	0,15	0,0530
15	Dry rooms	Area < 10 m ²	Regular	No	5,00	Yes	0,38	0,19	0,0607
16	Dry rooms	Area < 10 m ²	Regular	No	5,00	No	0,35	0,18	0,0607
17	Dry rooms	Area < 10 m ²	Regular	No	6,00	Yes	0,39	0,20	0,0661
18	Dry rooms	Area < 10 m ²	Regular	No	6,00	No	0,37	0,18	0,0661
19	Dry rooms	Area > 10 m ²	Regular	No	4,00	Yes	0,28	0,14	0,0530
20	Dry rooms	Area > 10 m ²	Regular	No	4,00	No	0,25	0,12	0,0530
21	Dry rooms	Area > 10 m ²	Regular	No	5,00	Yes	0,33	0,16	0,0607
22	Dry rooms	Area > 10 m ²	Regular	No	5,00	No	0,30	0,15	0,0607
23	Dry rooms	Area > 10 m ²	Regular	No	6,00	Yes	0,34	0,17	0,0661
24	Dry rooms	Area > 10 m ²	Regular	No	6,00	No	0,32	0,16	0,0661

nº	Local	Area	Type	Adhered	thickness (cm)	Reinforced	laborers (h/m ²)	Helpers (h/m ²)	Mortar (m ³ /m ²)
25	Humid rooms	Area < 10 m ²	Regular	Yes	2,00	No	0,59	0,29	0,0310
26	Humid rooms	Area < 10 m ²	Regular	Yes	2,00	Yes	0,62	0,31	0,0310
27	Humid rooms	Area < 10 m ²	Regular	Yes	3,00	No	0,63	0,31	0,0431
28	Humid rooms	Area < 10 m ²	Regular	Yes	3,00	Yes	0,65	0,33	0,0431
29	Humid rooms	Area < 10 m ²	Regular	No	3,00	No	0,66	0,33	0,0431
30	Humid rooms	Area < 10 m ²	Regular	No	3,00	Yes	0,68	0,34	0,0431
31	Humid rooms	Area < 10 m ²	Regular	No	4,00	No	0,69	0,34	0,0530
32	Humid rooms	Area < 10 m ²	Regular	No	4,00	Yes	0,71	0,36	0,0530
33	Dry rooms	Area < 20 m ²	Acustic	No	5,00	Yes	0,40	0,20	0,0607
34	Dry rooms	Area < 20 m ²	Acustic	No	5,00	No	0,37	0,19	0,0607
35	Dry rooms	Area < 20 m ²	Acustic	No	6,00	Yes	0,41	0,21	0,0661
36	Dry rooms	Area < 20 m ²	Acustic	No	6,00	No	0,38	0,19	0,0661
37	Dry rooms	Area < 20 m ²	Acustic	No	7,00	Yes	0,43	0,21	0,0760
38	Dry rooms	Area < 20 m ²	Acustic	No	7,00	No	0,40	0,20	0,0760
39	Dry rooms	Area > 20 m ²	Acustic	No	5,00	Yes	0,35	0,17	0,0607
40	Dry rooms	Area > 20 m ²	Acustic	No	5,00	No	0,32	0,16	0,0607
41	Dry rooms	Area > 20 m ²	Acustic	No	6,00	Yes	0,35	0,18	0,0661
42	Dry rooms	Area > 20 m ²	Acustic	No	6,00	No	0,33	0,16	0,0661
43	Dry rooms	Area > 20 m ²	Acustic	No	7,00	Yes	0,37	0,19	0,0760
44	Dry rooms	Area > 20 m ²	Acustic	No	7,00	No	0,34	0,17	0,0760

4. Conclusions

The authors have a large experience in dealing with efficiency in construction and also are often questioned about misunderstandings about construction costs. They believe construction efficiency can widely vary but the variation can be in a large part understood. Cost reference systems can be a very strong tool to discuss costs once they are carefully composed and represent nowadays technology and efficiency. In both presented cases, the users of the improved reference systems describe they can not only improve the figures resulting from its use but they can more easily discuss cost with other agents dealing with construction projects.

In both cases the produced reference system became an important tool to take decisions. Company A use it to discuss new buildings from the conception stage to the site decisions. And Company B is using its reference system to base all decision regarding to funding Brazilian construction.

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An Energy Expedition

Experiences of a Dutch collective of house owners aiming for energy neutrality

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Abstract

The municipality of Apeldoorn had polled the interest among its private home-owners to turn their homes energy neutral. Based on the enthusiastic response, Apeldoorn saw the launch of the Energy Apeldoorn (#ENEXAP) in 2011. Its goal was to convert to it technically and financially possible for privately owned homes to be refurbished and to energy neutral, taking the residential needs and wishes from occupants as the starting point. The project was called an Expedition, because although the goal was clear, the road to get there wasn't. The Expedition team comprised businesses, civil-society organisations, the local university of applied sciences, the municipality of Apeldoorn, and of course, residents in a central role. The project was supported by Platform31, as part of the Dutch government's Energy Leap programme. The #ENEXAP involved 38 homes, spread out through Apeldoorn and surrounding villages. Even though the houses were very diverse, the group of residents was quite similar: mostly middle-aged, affluent people who highly value the environment and sustainability. An important aspect of the project was the independent and active role residents played. In collaboration with businesses and professionals, through meetings, excursions, workshops and by filling in a step-by-step plan on the website, the residents gathered information about their personal situation, the energy performance of their home and the possibilities available for them to save and generate energy themselves. Businesses were encouraged to develop an integrated approach for home-owners, and consortia were set up by businesses to develop the strategy, products and services needed to meet this demand. On top of making minimal twenty from the thirty-eight houses in the project energy neutral, the ultimate goal was to boost the local demand for energy-neutral refurbishment and encourage an appropriate supply of services, opening up the (local) market for energy neutral refurbishment. This paper will reflect on the outcomes of this collective in the period 2011-2015.

Keywords: Energiesprong, #ENEXAP, LALOG, energy efficiency, local energy initiative, co-design

1. Introduction

As a result of the ongoing trend of individualisation, people are eager to actively influence and shape their own environment (Oostra, 2013). This paper will describe a case study in which owner-occupants did just that, no longer waiting until professionals were ready to deliver the kind of services and offers they wanted. The case study described in this paper was a recent Dutch project, part of Energy Leap (Energiesprong), an innovation programme commissioned by the Dutch Ministry of the Interior and operated by Platform31. The programme ran until the end of 2014, although parts were later extended to the end of 2015. The aim was to make various types of buildings energy-neutral and to boost large-scale initiatives. In the sub-programme LALOG (Lokaal Alle Lichten Op Groen) the owner-occupants themselves were looking for ways to challenge professionals to make their homes energy-neutral. The LALOG sub-programme provided support to groups of owner-occupants in six municipalities: Apeldoorn, Wageningen, Den Bosch, Hoorn, Amsterdam and Amersfoort. Goal was to convert at least 20 homes in each of these municipalities to energy neutral. It was a process of learning by doing by residents, builders, municipal officers, installation contractors, appraisers and other professionals. In this paper we will focus on the experiences of the Energy Expedition in Apeldoorn, also known as #ENEXAP.

2. Theoretical framework

There are basically two main bodies of knowledge relevant as theoretical framework. One is the literature on innovation management in which innovation is seen as a combined technological and economical phenomenon looking at companies (e.g. Von Hippel 1986, Chesbrough, 2006), entire supply chains (e.g. Vrijhoef, 2011) or the industry as a whole (e.g. Lundvall, 2008). Most relevant in the context of the case study are the theories focussed at upscaling from an innovative technological niche towards uptaking in the current regime (Strategic Niche Management (SNM)). The other body of knowledge relevant for this paper is the world of grassroots innovations and community action directed at fundamentally rethinking all aspects of our current society in order to build an intrinsic sustainable way of living. These two knowledge domains not only represent two different scientific communities, they represent fundamentally different groups of people with distinct discourses and practices in real life as well.

2.1 Innovation management

For innovation at the level of (a part of) an industry, the term transition is generally used. The perspective of social-technical transitions has emerged from evolutionary economics (Nelson & Winter, 1977; Dosi, 1982). From studies of former mayor changes in society e.g. the transition from horse carriage to rail and steam trains, from cottage industry to mass fabrication, insights have emerged regarding the importance of experimentation, multi stakeholder learning, coevolution of technologies, new ways of organisation, rules & regulations and financial systems. This resulted in theories of Strategic Niche Management and Multi Level Perspective (Geels & Kemp, 2007; Loorbach & Rotmans, 2006), which can be used to analyse current innovations. The rationale in these theories is that innovations start in specific niches, but their

further development is highly dependent on other changes in the different societal levels (micro, meso and macro). SNM describes emerging innovative niches becoming mainstream in combined dynamic social and technological systems.

The innovation management perspective focuses on the formation of niches in which innovations can flourish. In this perspective, residents would learn to use their purchasing power to get the innovations they want, in order to be able to improve the energy performance of their homes towards energy neutral. According to Strategic Niche Management, three additional processes are important when developing a successful technological niche (Kemp et al., 1998):

- The articulation of expectations and visions that would provide direction to the learning process of parties involved. The expression of visions and expectations would also help to attract attention from the necessary stakeholders and legitimate their involvement and support.
- Construction of social networks. Interaction between different stakeholders is needed to collect the required resources (time, expertise and money) and commitment.
- Learning on multiple aspects: (1) Technical aspects and design specifications, (2) Market and user preferences, (3) Cultural and symbolic meaning, (4) Infrastructure and maintenance networks, (5) Industry and production networks, (6) Regulations and government policy and (7) Societal and environmental effects.

2.2 Grassroots innovations & community action

Until recently, the attention for innovation from the voluntary sector and local communities was not really taken into consideration despite decades of initiatives at local level. As a result, little is known about the success factors and the way these grassroots innovations take place. The innovation in these bottom-up initiatives consists mainly of social innovation. Seyfang and Smith (2007) define grassroots innovation as follows:

“Grassroots innovations are networks of activists and organisations generating novel bottom-up solutions for sustainable development and sustainable consumption: solutions that respond to the local situation and the interests and values of the communities involved.” (Seyfang & Smith, 2007, p.585)

Local initiatives usually construct alternative systems in which production, distribution, marketing, retail and consumption are connected in a novel way. Since the publication of the Limits to Growth report (Meadows et al., 1972) environmental movements emerged that experimented with different ways to minimize their ecological footprint. Inspired by Schumacher’s ‘Small is Beautiful’ (1973) pioneers also addressed housing with appropriate technology, i.e. adopting a scale and complexity of technology appropriate to its setting. Seyfang and others translated the conclusions of their academic work in ten important statements directed at policymakers in relation to local energy initiatives, aiming to support innovation from these local initiatives. Community Energy is (grassrootsinnovations.org):

1. Critically important for sustainable (energy) transitions (Hielscher et al., 2013)
2. A diverse, growing, grassroots-led movement (Seyfang et al., 2013b)
3. About more than just sustainable energy (Hargreaves, 2012)
4. Thrives on local enthusiasm, but can't rely on goodwill alone (Hielscher, 2013)
5. As much about soft skills as well as hard technology (Seyfang et al., 2013)
6. Not yet being taken seriously enough by government (Seyfang et al., 2013)
7. Connected to community and sustainability networks (Seyfang et al., 2013)
8. Benefits from strong support networks and organisations (Hargreaves et al., 2013)
9. Reaches parts of society the private sector alone cannot reach (Martiskainen et al., 2013)
10. Demands flexible and tailored policy support at all levels (Hargreaves et al., 2013)

2.3 Integrated framework for analysis

The two frameworks of innovation management and grassroots community action were integrated into one integrated framework to analyse #ENEXAP:

- Articulation of expectations and visions
- Construction of social networks: (1) Diversity of actors, institutional forms and activities (2) Social capital (networks of support), human capital (skills), organisational capital (know how), financial capital (3) Contacts on local, regional and national levels and (4) Sector support infrastructure
- Learning on multiple aspects: (1) Technical aspects and design specifications (2) Market and user preferences (3) Has different meaning to the people involved (4) Infrastructure and maintenance networks (5) Industry and production networks (6) Regulations and government policy, and (7) Learning by doing, face-to-face support and mentoring.

3. Purpose & methodology

This paper will reflect on the outcomes of the collective in Apeldoorn. The subsidized #ENEXAP project ran in the period 2012 - December 2014. The period that is described in the paper is October 2013 until June 2015. The description of #ENEXAP case is based on the authors' experience as part of the initiative. Oostra was member of the #ENEXAP board from November 2013 until April 2015, Been was secretary and resident advisor for #ENEXAP from March 2013 until June 2015. The material on which the analysis is based derives from action research, board meetings, occupant meetings, meetings with Energy Leap, study meetings for the companies and conversations with people related to #ENEXAP. First a general description of the case study will be made. The next sections will be dedicated to the description of the results and the analysis of the results before ending with the summary.

4. Case description of Energy Expedition Apeldoorn

In 2011, Apeldoorn saw the launch of the Energy Expedition Apeldoorn (#ENEXAP). The municipality of Apeldoorn was curious to find out how many of its residents were interested in making their homes energy neutral, and placed an announcement in the local newspaper, 'Stadsblad'. A large group of owner-occupants came to the meeting. This resulted in a group of 33 households that started as part of the Expedition in May 2011, growing to 38 households during the process. The Expedition was supported with a LALOG subsidy from 2012 until December 2014. LALOG's direct goal was to refurbish a minimum of 20 homes making them energy neutral, taking as starting point the input from occupants. The overall ambition was to make it technically and financially feasible for owner-occupants to retrofit their home, starting with this small group and from there on boosting the local demand for energy-neutral refurbishment and encourage an appropriate supply of services. The #ENEXAP team comprised of local residents, businesses, civil-society organizations, the municipality of Apeldoorn and the local University of Applied Sciences, Saxion. These different groups all played a constructive role in carrying out the Expedition. Owners fuelled professionals with their ideas and wishes; professionals helped owners to make their wishes achievable. In the next paragraphs, the roles of the key players in the Expedition are described.

Table 1: Roles of the different stakeholders in #ENEXAP

Stakeholder	Role
<i>Owner-occupants</i>	<i>(1) The occupant-owners played an active and vital role in shaping the process. The board of #ENEXAP consisted merely of residents. After the founding of the Expedition, residents formed working groups, which were started to address different relevant issues. (2) Residents actively monitored the energy consumption in their own homes. They put a lot of effort in making their residential wishes explicit. They were guided in this by a course and a specially developed step-by-step plan. (3) Residents were actively involved in the development of solutions by professionals.</i>
<i>Advisers</i>	<i>(1) Several professionals brought in their knowledge on sustainability by presenting on one of the meetings for occupants or by giving a tour. Because of the innovative character of the initiative they were often willing to do so for free. (2) Additionally professional support was hired for organisational issues, but also for communication strategy and the development of a magazine. Professional support was also hired for executing three EPA Super Luxurious analyses, matching financial advice and support for the Board.</i>
<i>University of Applied Sciences</i>	<i>The university was asked to develop and organize two courses to the residents as well as the consortia. The first course was intended to help the occupants to articulate their requirements, how to formulate these to professionals and how to weigh different solutions e.g. financially with the principles of Total Cost of Ownership. During the course for professionals the focus was on how to deliver an integrated offer to this specific group of clients. A second course for professionals was directed at how to make an energy fingerprint of a dwelling, how to respond to a wide range of demands from clients by using principles of mass-customization and what is involved in providing a warranty on energy performance after a retrofit. The university was also part of the Board.</i>
<i>Companies & consortia</i>	<i>At first large contractors were linked to #ENEXAP. They dropped out because their primary interest in larger building assignments, e.g. block by block retrofitting of terraced houses with a high level of standardization. In the Expedition however, the houses are of varying types, spread around Apeldoorn. The companies that remained linked were local SME's. They made integral plans for energy neutral refurbishments, which was highly challenging for them, because of a lack of knowledge necessary for these assignments. #ENEXAP handed the SME's knowledge through courses and contact with a group of interested clients.</i>
<i>Energy coaches</i>	<i>The energy director helped residents to make a choice for the consortium that fitted their requirements best and helped owner-occupants in requesting quotes and the evaluations of these bids. The energy director was meant to be the intermediary between owner-occupant and companies. An auditor was appointed as supervisor to offer extra safety for the participants, by providing an extra check on the plans. In practice the roles of energy director and auditor were combined. For the residents group coached by a specific energy director the other functioned as auditor, and vice versa. Instead of 'energy director' and 'auditor' the name of 'energy coach' was therefore more appropriate.</i>
<i>Municipality</i>	<i>(1) The municipality proved to be an important party since they took the initiative for the start of the</i>

	<i>Expedition. They decided to make an inventory of residents interested in energy neutrality. (2) They were also the party that applied for a LALOG grant (€ 285.000) that was combined with money from SLOK (€ 33.265) and money from the municipality's budget (€ 6.000). Also money from the EU project ACE was available for product development and feasibility studies (€ 84.500) (Apeldoorn, 2012). (3) The municipality was part of the Board of #ENEXAP and (4) formed the link to the national energy programme.</i>
<i>Energy Leap</i>	<i>(1) Energy Leap organised several meetings to exchange information between the stakeholders in the municipalities involved in the LALOG programme. (2) Energy Leap also made links to other parts or parties in the Energy Leap programme that were of interest for #ENEXAP. For example the expertise was shared, that was being developed around the topic of energy performance guarantees (e.g. the standard contract) in Rapids, another sub-programme directed at dwellings. (3) Experts were invited to give presentations at either one of the occupants meetings, as part of the course made available to the local SME's or for special sessions. #ENEXAP was asked by Energy Leap to host one of the field trips for appraisers. In this field trip appraisers from around the country were asked to make an estimate of the dwelling before and after the retrofit in order to establish how an improvement in energy performance would translate in additional financial value of the dwelling.</i>

5. Results

The overall result of the Apeldoorn Energy Expedition was that in June 2015, after being roughly four years en route, five houses were well on their way towards becoming energy neutral. Three consortia of local SME's were formed, and residents had started to save considerably on energy.

Table 3: Goals of the LALOG program vs. results of #ENEXAP

Goals of LALOG	Results of #ENEXAP	Remarks
<i>To put owner-occupants central in the development program</i>	<i>Owner-occupants were in the lead.</i>	<i>This worked very well for focussing on the topics relevant for owner-occupants. It proved to be a hindrance for the continuation of the program after the end of the LALOG subsidy.</i>
<i>De-burden occupant-owners in their search of energy neutrality</i>	<i>The formation of a new consortium of companies focussed at the retrofitting of owner-occupant housing, training of 3 local consortia and the development of an approach that would fit both clients and entrepreneurs.</i>	<i>Proved to be difficult since the innovation leap required was very steep for the companies involved. These companies operated in a context where business and investment money was scarce. For them it proved to be very difficult to commit to the required product and process innovations.</i>
<i>20 dwellings energy neutral</i>	<i>June 2015 5 #ENEXAP houses were energy neutral or were in the process of becoming energy neutral.</i>	<i>It was not easy to reach this goal. There was only one other LALOG municipality that succeeded in realizing 5 energy neutral dwellings (Energiesprong, 2014).</i>
<i>Secondary – To integrate higher comfort level, healthier indoor climate and an increase of functionality with a considerable reduction of the energy bill</i>	<i>A combination with other requirements of the clients proved to be key during the program. Important additional requirements were: additional space, conversion of bathroom and/or kitchen and future proofing of the home.</i>	<i>It turned out, that the secondary goals of the LALOG program were essential to the occupant-owners. In case the consortia tried to eliminate an important secondary requirement of the client, the process came to a halt.</i>
<i>Secondary - Promote the use of environmentally friendly products</i>	<i>Attention was given to environmentally friendly products in presentations given at occupants meetings, in excursions and it was the expertise of one of the energy directors in #ENEXAP.</i>	<i>This was regarded as a matter of taste within #ENEXAP. To some of the occupant-owners this proved to be important, mainly because environmentally friendly products are associated with a healthy indoor environment.</i>
<i>Secondary - Increase of the value of the dwelling</i>	<i>This topic was not so much addressed in the sessions between occupants and companies since they themselves were not able to answer questions on this topic. Neither was the local broker.</i>	<i>This knowledge had to be developed. Energy Leap understood the importance of this question and organised two field trips of appraisers. One was hosted by #ENEXAP.</i>
<i>To draw a business case for the companies to allow for continuation of energy neutral retrofitting after the duration of</i>	<i>The following was developed in order to smoothen energy neutral retrofitting:</i> <ul style="list-style-type: none"> • <i>Step-by-step plan for the occupant-owners as a</i> 	<i>The companies were focussed on making money from the start, as this is the way they are used to do business. They were not accustomed to heavily invest in the</i>

#ENEXAP	<p><i>means to aggregate all the information necessary about their homes and current energy consumption.</i></p> <ul style="list-style-type: none"> • <i>A financial check and a website to structure and exchange of all the information gathered.</i> • <i>Courses to help occupants to make their requirements explicit and for companies to be able to develop an integrated approach and matching offers.</i> • <i>A one-stop-shopping approach towards clients, which includes scrum-sessions at the kitchen table with all disciplines present to draw up quickly a tailor-made solution.</i> • <i>A coaching approach to support companies during their first assignments with clients.</i> 	<p><i>development of a new (industrialised) market approach, while #ENEXAP was trying to focus on opening a bigger market on the long term for which new retrofitting concepts and approaches needed to be developed. For Energy Leap the experiences from the LALOG programme were a reason to design new subsidy programmes: Rapids Rental and Rapids Purchase.</i></p>
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6. Analysis & discussion

In this paragraph we analyse the case study by confronting process and results with the integrated framework introduced in paragraph 2.3.

ARTICULATION OF EXPECTATIONS & VISIONS

The structure of the experiment was designed to support residents: the course, the interactions during kitchen table conversations, but also the discussions that emerged around presentations and excursions all helped to articulate expectations and visions. This stimulated the owners to aim high and ask for innovative solutions, be fitting their situation and demands, thereby stretching the abilities of the consortia. So the group of owners demanded innovation, but on the other hand they requested warranties on energy performance. This combination was hard on the consortia to achieve, however, the group would not let go of this high ambition.

CONSTRUCTION OF SOCIAL NETWORKS

Diversity of actors, institutional forms and activities - In a period of three years, different groups of residents, professionals and intermediaries were brought together to work on the goals set: zero energy houses and fulfilled residents wishes, while at the same time paving the road for a widespread of retrofitting in the nearby future. This required bridging the gap between residents and professionals, which both speak a different language because of different knowledge levels, perspectives and goals. During the course of several meetings, workshops and excursions residents and professionals acquired knowledge, both technical and about the perspective of the other group, and learned how to fill in their role. In the mean time, several products were developed, from which the most important one is the step-by-step plan. In working groups, residents and professionals with different expertise worked together on specific themes. There were several working groups for technical issues, EPA Super Luxurious, finances and communication. The communication group made a website to monitor progress and to serve as a discussion platform. Courses were held to support both residents and professionals in finding their way. Outcomes were that residents could better articulate their wishes and needs, a new consortium was formed and approaches were developed for the professionals to be able to make multi-disciplinary offers.

Social capital (networks of support), human capital (skills), organisational capital (know how), financial capital - There was a network of similar initiatives like #ENEXAP with initiatives in Amsterdam, Amersfoort, Wageningen, Den Bosch and Hoorn, that met once in a while. Also there were discussions with the Energy Leap programme. This provided a network to exchange ideas and inspiration. It also helped to see that others were also struggling to meet the goals set at the beginning by the Energy Leap programme. Because of the diversity of actors involved, people willing to give lectures and advise, and money from the programme to hire missing expertise, knowledge and skills needed in development were available.

Learning by doing, face-to-face support and mentoring - The goal was clear but the road to get there wasn't. This fostered learning by doing. The pilot EPA Super Luxurious e.g. turned out not to work as it was intended. The contractors did not directly translate the reports written by energy advisors into matching offers. Instead these companies either presented alternatives to the solutions proposed, or just started the work all over again. Because of the community feeling, people remained focused on the goals, although it was sometimes hard to find the right course. The social network helped to keep the parties involved on track when confronted with setbacks. The local setting, the organized activities and the energy coaches made regular face-to-face support available for both residents and companies. The energy coaches were mentoring both residents and companies on how to formulate interesting offers.

Contacts on local, regional and national level - Local contacts were organised within the Expedition and by reaching out to the expertise required. Energy Leap, the municipality, Saxion and professionals involved provided contacts on regional and national level when necessary.

Sector support infrastructure – Additionally, the municipality made hours available from a civil servant. And of course there were as well hours available from the different (professional) volunteers. This made it possible to erect an infrastructure to support interested owner-occupants in converting their own dwellings to energy neutral as well as to support local companies interested in exploring this new emerging market. Most of this supporting infrastructure is already described above.

LEARNING AT MULTIPLE ASPECTS

Technical aspects and design specifications - Technical aspects received a lot of attention in presentations at meetings, excursions and kitchen table conversations between consortia and owner-occupants. The kitchen table conversations and the first course helped in making the requirements from the occupants explicit. This formed the basis for the design specifications.

The Plugwise system was used to measure the consumption of electricity. It helped to create awareness on energy consumption necessary to operate different appliances in the home. For most people it was a complete surprise to see what the usage of a specific appliance meant, e.g. the electric boiler in the kitchen, the tap with boiling water or the electrical floor heating. This insight was essential to take further steps, e.g. changing equipment or just switching devices off.

Market and user preferences - The experiment can be seen as a way of developing a new market. #ENEXAP was an experiment, a pioneer project. The market was, and still is, learning how to accommodate clients' wishes and requirements when retrofitting individual occupant-owned houses to energy neutral in an integral way. At the same time, user preferences within this project proved to be very specific, being influenced by specific housing types and lifestyles. Therefore, every solution had to be tailor-made. For the companies involved it proved to be very challenging to develop matching supply for energy neutrality in combination with the other requirements. In board meetings it was also discussed that the consortia should integrate the wish of several occupants to think about combinations of professional work and DIY. The majority of the board saw this as a risk to overburden the consortia and the idea was therefore put aside.

The initiative has a different meaning to the people involved - The Expedition was about being adventurous: developing unexpected roads together, while enhancing sustainability. Owner-occupants had various reasons to take part in #ENEXAP. During the experiment it became clear that the idea of a sustainable, environmental friendly home with a small ecological footprint was an important driving factor, but not for all. There were also people part of the programme that were technologically interested, or focussed at reducing operational costs of living. This underlines outcomes of other research about the profile of people interested in energy neutrality (e.g. Hensen & Westerhof, 2013). For a part of the group it became a sort of hobby: improving their house, replacing e.g. lighting and refrigerator or just switching off a close-in boiler or waterbed, and sharing experiences with co-participants. The financial investment made by occupant-owners didn't need to be earned back completely by lower monthly energy costs; also the feeling of being part of this new, sustainable movement and acquiring more comfort or other functionalities were rewarding for the people involved.

Infrastructure and maintenance networks – During the training attention was given to maintenance and performance guarantees. This appeared to be very challenging for the consortia. External expertise from the Energy Leap programme was made available. In the end this did not lead to concrete offerings including maintenance and performance guaranties.

Industry and production networks - The technical innovation expected from the Expedition did not materialize. The local SME's were not equipped to create specific innovative products or designs. The industry able to come up with innovative products was not part of the Expedition. LALOG turned out to be an important lesson for the Energy Leap programme that they needed to create a different framework in order to realise the change in industry required for cost effective implementation of retrofitting at a large scale. This finally resulted in a new sub-programme: Rapids.

Regulations and government policy - The local government took their citizens seriously, since they initiated the #ENEXAP in order to reach governmental goals. Nevertheless, policies on for example permits for refurbishing were not able to provide the flexibility required right away. The local government tried to work with the occupant-owners to make the process of permit acquisition as smooth as possible. And discussions were started around topics like whether trees

should be taken down in neighbourhood streets that would be blocking sunrays to reach solar panels and about the conditions necessary to meet flora & fauna legislation.

Societal and environmental effects - In the Netherlands there are approximately 7.2 million dwellings, among which a lot of terraced houses build between 1946 and 1991. The municipality of Apeldoorn has 156.960 inhabitants and consist of 67.780 households (Stadindex, 2015). To give an indication of the amount of energy that can be saved: 1.04 PJ per year by retrofitting 10 % of the Dutch housing stock to zero-on-the-meter in a period of 10 years. The average energy consumption per dwelling in the Netherlands is 1440 M3 natural gas and 3440 kWh of electricity (Nibud, 2015). This is 53 GJ per dwelling. When 10 % of housing stock will be retrofitted to zero-on-the-meter in 10 years (19,650 a year) it will represent a saving of 1.04 PJ of fossil energy per year. In the Netherlands, the gross revenue per employee per year was 310,000 Euro in 2013 (EIB, 2013). By linking the above gross turnover of 8.8 billion per year and the gross turnover per employee in the Netherlands, it will result in 28,000 jobs per year. For Apeldoorn only, the effects will be scaled to ratio of course.

Is as much about soft skills as well as hard technology - This experiment shows that technical knowledge alone was not enough to reach the goals of this experiment. The courses and the energy coaches had to guide the process and translate between both clients and companies. The road to success was not easy, mainly because next to goodwill, also knowledge both technical and process related, was needed to guide all the parties in the right direction. Also the process by which the clients were approached by the consortia, the so-called customer journey, had to be addressed by the energy coaches. Scrum sessions were introduced to speed up the process and to diminish the time needed by the companies to formulate a tailor made offer.

7. Summary & concluding remarks

The developments in the Energy Expedition addressed aspects of both views mentioned in the theoretical framework: innovation management and grass roots innovations. Both emphasize the construction of a new community, or niche, focussed at a mutual goal and room for learning. In the integrated framework this was translated in the backbone of the three pillars of the integrated framework constructed in section 2.3: goal articulation, social networks and learning. All three have played an important role in the functioning and results of the Expedition.

Starting point was the articulation of the ambition of energy neutrality. The Expedition stimulated owner-occupants to articulate their specific expectations and demands. Their high ambition level stimulated the consortia to give their best. They started developing one-stop-shop formulas and integrating existing products into customized solutions.

The programme in itself formed a coalition of occupant-owners, companies and facilitating parties. This coalition shared experiences and expectations for a period of three years e.g. during meetings, excursions and courses. This social network was the carrier and basis for the meetings, working groups and other interactions. Furthermore, the network helped to survive setbacks and to maintain drive and enthusiasm.

The new and dynamic network that was constructed around #ENEXAP provided the necessary conditions for learning. Learning was not so much on technical aspects as on social innovation, like market and user preferences, speeding up of the offer preparation process and soft skills. In relation to market preferences, it was learned that owner-occupants demanded tailor-made solutions based on their specific situation. An important lesson from this initiative is that for consortia focussing on the market of retrofitting owner-occupant owned dwellings it is essential to look at all requirements: energy performance, comfort level, future proofing of the home and other additional requirements, and to do this in an integrated way. Moreover, the owner-occupants want a warranty on energy performance. Soft skills proved to be key to bridge different knowledge levels, perspectives and goals. Finally, it can be concluded that the combination of expertise and roles necessary to upscale the retrofitting of occupant-owned dwellings requires even more integrated value chains. It also became clear in #ENEXAP, as in LALOG that disruptive product innovations are key to arrive at affordable energy retrofitting solutions necessary to realise large scale retrofitting of owner-occupant owned dwellings. New sub-programmes, Rapids Rental and Rapids Purchase were initiated to accomplish just that.

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The energy concept of a post-2020 housing development zone – economic assessment

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Abstract

This paper presents a housing development project in Tampere. Part of the construction of the zone will take place after 2020. The buildings constructed after that in the zone must be so-called ‘nearly zero’ buildings. Another significant constraint is the location in cold climate.

The project examined several different energy solutions. They differed from each other in the way heat and electricity was produced for the area. In these solutions, heat was either transferred to the area via traditional district heating, produced using heat pumps or solar thermal collectors. The electricity solution, on the other hand, was either concentrated, i.e. a power grid, or self-produced using photovoltaic panels.

Energy consumption was calculated using dynamic IDA-ICE simulation software, which used as input data hourly consumption profiles of an adjacent zone. The structures of future houses are in compliance with the energy efficiency targets set for the period in the National Energy Path. Primary energy and greenhouse gas emissions were calculated using local coefficients. The economic review covered the calculation of the payback period, the internal rate of return and the total cost.

Geothermal energy as a source for heating and electricity supplied by the network turned out to be the competitive alternative compared to traditional system, whether the decision was based on primary energy consumption, greenhouse gas emissions or economy.

Keywords: nzeb, RES, heating, electricity, economy

1. Introduction

The target area is located in Tampere. According to Köppen's climate classification, Tampere as well as Finland wholly belongs to the temperate zone with cold, wet winters with sunlight marginally. The mean temperature of the warmest month is no lower than 10°C and that of the coldest month no higher than -3°C.

The area in question is an abandoned industrial area that will be rebuilt to residential use. The industrial area was sold to a property developer who has planned the area in cooperation with the city. A neighbourhood construction cooperation model known as “collaborative urban planning” (Nykänen et al., 2007) has been applied to the planning process. In the model, the planning of the residential area and town planning are carried out jointly by the construction company and the planning organisation of the city. This procedure is suitable for projects where special objectives have been set for an area, such as energy efficiency or higher-than-usual quality.

In the target area, such objectives had been set precisely for energy efficiency and customer orientation. Communications with the neighbourhood and potential residents have already been close during the town planning stage. The planning is otherwise proceeding normally with regard to background investigations and hearings that have also caused changes to the plan. Among other things, the final floor area (218 000 m²) is lower than the first proposal.

The floor area of the residential buildings is large compared to the local housing market. For this reason, the construction is distributed over a period of ten years. This means that some of the buildings will not be completed until after year 2020, when all construction in the Member States of the European Union must be nearly zero energy buildings. A nearly zero energy building refers to an energy-efficient building as defined in the Energy Performance of Buildings Directive (2010). The required amount of energy that is nearly non-existent or extremely small should be covered to a large extent with energy from renewable sources, including renewable energy generated on-site or in the vicinity of the building.

2. Project goal

The main goal of the project has been to find a suitable energy system for the new residential area comprising near zero energy buildings. The suitability has been examined from several different perspectives. These make up the project's sub-goals or examinations from 1) the technical perspective (energy production), 2) the environmental perspective (greenhouse gas emissions) and 3) the financial perspective (investments and expenses during service life). This conference paper concentrates on sub-goal three, or financial examinations. Sub-goals one and two are discussed only to the extent to which they affect sub-goal three. It should be noted that the issue in question is the selection of a district-level energy system. Building-level solutions have been excluded, although the district systems might require their modification.

3. Research method

The energy consumption of the buildings in the area has been assumed to comply with the currently valid regulations until the year 2020, after which consumption is at the zero energy level. The hourly energy consumption profiles have been adopted from the neighbouring area, where new apartment blocks have been built over the last couple of years. The availability of light and warmth from the sun is similar in these two residential areas. It is also likely that the area will attract households of a similar type as the previously built area.

Several solutions for satisfying the need for energy have been investigated, taking into consideration the aim to increase the share of renewable energy in the buildings' energy consumption. Information on renewable energy yields has been received from both the industry and studies by our own research organisation.

3.1 Evaluation of solutions

The first financial examinations focused to the alternative decentralised solutions that use different forms of renewable energy. These calculations were done using a calculation model developed in the Renewable Energy Multitechnology Mix -project (REmix [www-pages](#)). The tool uses the basic key indicators of investment calculations (the payback period, the internal rate of return (IRR), and the net present value (NPV)). The calculation model also supports taking into consideration synergies resulting from the parallel development of several different forms of energy already from the planning stage. The model was developed to support the decision-making of, in particular, the municipal sector, so indirect effects can also be included in the calculation.

The basic idea of the model is to compare (at least to a certain extent) the solution implemented using renewable forms of energy to a "business as usual" solution comprising district heating and grid electricity. This assumption is extremely well suited to investments for replacements, where the current solution is based on district heating and grid electricity. The assumption can also be justifiably used as a comparison alternative in new construction areas, where district heating and grid electricity would be easily obtainable.

The payback period is the most commonly used investment calculation method, as it is simple to use and easy to understand. In this case the investments are made in equal parts over a period of ten years. The assumption is that the price of energy will increase and the price of technology decrease, each part of the investment will be made in a slightly different price environment.

The internal rate of return, in turn, indicates the discount rate at which the net present value of the investment is zero. The investment can, thus, be considered to be profitable if the internal rate of return is higher than the required rate of return for the capital or discount rate used by the operator.

3.2 Total cost comparison

The second calculation focused to the investment and the operating costs of all alternatives. These total costs have been calculated over a period of 25 years applying methodology framework for calculating cost-optimal levels (2012/244/EU). To be noted that the evaluations are done from the perspective of the Limited Liability Housing Companies.

4. Energy solutions and calculation assumptions

4.1 Alternative heat carriers for an energy system

Geothermal heat (GTH) is energy absorbed into the ground and water, mostly originating from the sun. GTH can be utilised with a heat pump regardless of the time of year (Lauttamäki et al., 2013). The pump collects heat from a drilled heat well that is typically around 200 m deep, or from a heat collection field installed either to the ground (depth one metre) or bottom the lake (depth two metres). The pump consumes electricity during the process, and the amount of heating energy it produces is typically around three times the amount of electricity it consumes.

Solar energy can be collected directly with **solar thermal collectors (STH)** or **photovoltaic panels (SE)**. In Northern Europe, the problem in their utilisation is that the heat and electricity are generated at a different time than when they are used. Solar energy is most abundant during the summer, when its only application is heating household water (Pesonen et al., 2012). Both solar thermal collectors and PV are used as a secondary system. In order to maximise the power from the panels, they should be positioned facing south. Solar electricity is most cost effective when utilised right away. Storing electricity is not yet economically profitable due to the high price of batteries. The panels have an efficiency of around 10 to 20 per cent, which means that around 100 to 200 kWh/m² of the annual solar radiation energy (1,000 kWh/m²) can be converted into electricity.

A **district heating (DH)** network comprises power plants and pipelines going into the heating stations of the buildings. Heat is transferred from the warm water entering the heating stations to the buildings' own heating systems. District heat can be produced most energy-efficiently in Combined Heat and Power (CHP) plants producing electricity and, as a side product, heat that is then fed into the district heating network. District heating can also utilise incinerated waste and industrial waste heat (District heating –site).

Electricity network (NE) is a basic service. The task of the electricity network is to transmit the electricity produced in power plants to electricity users.

4.2 Examined alternatives

Of the alternatives described above, five different combinations were chosen for further examination (table 1; figure 1).

- 1 BAU: District heating and electricity from the national network.
- 2A GTH, NE, STH & SE: Geothermal heat (50 per cent of the peak power requirement) and network electricity complemented with solar heat (ten per cent of the roof area) and solar electricity (an optimal amount)
- 2B GTH & NE: Geothermal heat (50 per cent of the peak power requirement) and network electricity
- 3A GTH, DH, NE & SE: Geothermal heat (35 per cent of the peak power requirement is fulfilled by collector field) complemented with district heating, grid electricity and solar power (an optimal amount)
- 3B GTH, DH & NE: Geothermal heat (35 per cent of the peak power requirement) complemented with district heating and network electricity

Table 1. The input of energy carriers by examined solutions.

	BAU	2A	2B	3A	3B
District heating	56 %			28 %	28 %
Geothermal heat		40 %	46 %	22 %	22 %
Solar heat		7 %			
Network electricity	44 %	43 %	54 %	44 %	50 %
Solar electricity		10 %		6 %	

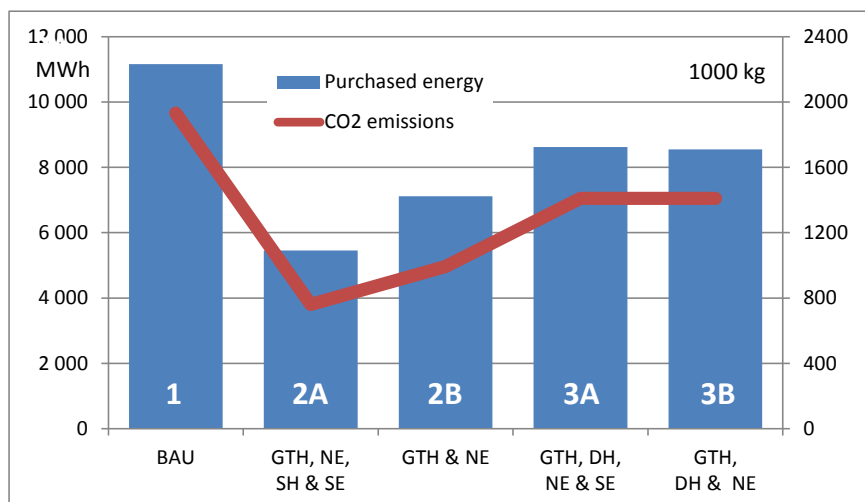


Figure 1. Purchased energy and greenhouse gas emissions of examined solutions.

Connecting the buildings to the local district heating network and the national electricity network (alternative 1) is the "business as usual" alternative. In alternatives 2A and 3A, the aim is to increase the share of renewable energy through nearby energy production. Harvesting solar energy has been eliminated from alternatives 2B and 3B.

Geothermal heat (2A, 2B, 3A, 3B) covers most of the need for heat, but their power is not enough for heating the buildings during the coldest weather during the winter. These peak consumption periods are covered by support heating. In the 2A and 2B alternatives, the support heating is produced through electricity network, and in the 3A and 3B with district heating. The primary energy consumption of the alternatives is presented in Figure 1.

The energy consumption of the buildings is identical in all alternatives. The differences in the consumption of purchased energy (figure 1) are a result of the efficiency of the energy production and how much free energy and renewable energy can be used.

4.3 Calculation assumptions

In this project, the basic assumptions and the price change scenarios were decided jointly with the research group and project's steering group. The key calculation assumptions:

- Price of district heat EUR 80/MWh including energy + monthly fees + VAT 24 % (Energy prices -site)
- Price of grid electricity EUR 120/MWh includes energy + transmission + monthly fees VAT 24 % (Energy prices -site)
- Energy price development 2 % per year and 4 % per year
- Renewable energy technology -2 % per year except solar power technology -5 % per year
- Operating and connection costs development 2 % per year
- The surplus energy produced is either wasted or used free of charge.
- Time horizon 25 years
- The residual value of the investment is EUR 0

The moderate energy price, operating and connection costs scenario (2 %) is in line with the general development of consumer prices in the near history. In the alternate scenario (4 %), the price of energy is assumed to increase faster than the general consumer prices.

Forecasting the development of energy price over a 25-year period is very challenging as it is affected by so many different factors (taxation, energy policy, state of the global economy, etc.). A 50-year horizon could also have been used, but energy price development forecasts reaching just 25 years into the future already include a great deal of uncertainty, making an even longer time period difficult to justify. Furthermore, investments usually have to pay for themselves and show profitability after a significantly shorter time period than 25 years.

A 25-year horizon is so far away that the low residual value at the end of the period does not have much impact on the calculations. Additionally, determining the residual value 25 years into the future is very challenging, as technological solutions are rapidly developing.

In the future nearby production surplus energy can naturally have its use, if selling it into the network becomes possible and/or advancements are made in energy storage technologies (e.g. batteries). In its part, this would improve the profitability of renewable energy investments.

The price trend of renewable energy solutions has been downward in the 2000s, particularly in the case of solar power. This development has been assumed to continue for the next five to ten years in the calculations.

In alternatives 2A and 2B, all investments are made in parts over a period of ten years in accordance with the demand for energy (it is assumed that construction takes place at an even pace over ten years). In reality, the construction will probably not take place at an even pace, but this assumption was made in order to make the calculation clearer.

In alternatives 3A and 3B, the geothermal system is built as a one-time investment, and the district heat and solar electricity investment (in alternative 3A) within five years in accordance with demand (it is assumed that construction takes place at an even pace). Alternatives 3A and 3B have options for starting the implementation either immediately or after five years. The solution can be deployed either in the half of the area that is completed first or the half completed last. The price environments between these options are different to such a degree that it must be taken into consideration in the calculations, too.

5. Results of examinations

5.1 Is it worth invest earlier than later?

Figure 2 depicts the payback period for the different solutions of alternative 2 for the part investments made during the first and tenth years. The payback periods of the first and last part investment differ very significantly from each other. The payback period of the investment as a whole is somewhere between these extreme values. It can also be stated in the 2B solutions, the payback period is shorter than in the 2A solutions, i.e. the solution with just geothermal heat leads to a better end result in the economic sense than when it is combined with solar heat and electricity.

According figure 2 the payback period is shorter the larger the annual increase in energy price is. Correspondingly, a part investment made in the tenth year leads to a shorter payback period than the part investment made in the first year. This is explained both by the increase in the price of energy and the decrease in the price of technology. The figure also shows that the time of the part investment (first vs. tenth year) has a clearly larger impact on the payback period than the increase in the price of energy (2% vs. 4%). The price environment is naturally most favourable with a tenth year part investment and a 4% assumed increase in the price of energy.

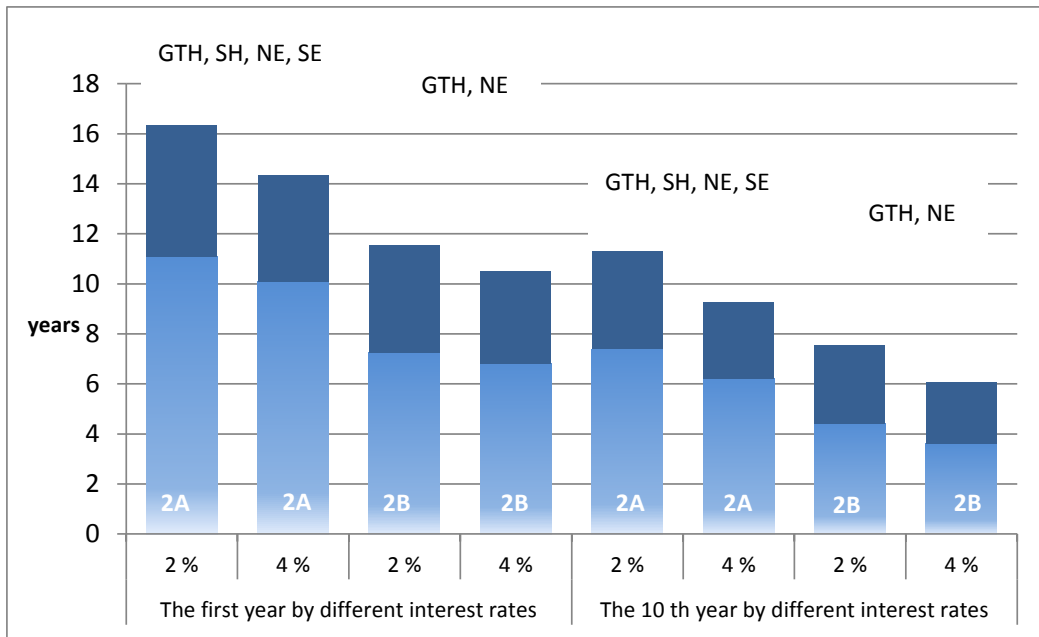


Figure 2. Payback period (years) is shorter without solar energy both in the first year's and the 10th year's investment even the price erosion has been taken account. Price range is $\pm 20\%$ (dark part of columns).

It can be seen in Figure 3 that the internal rate of return is higher the larger is the annual increase in the price of energy. The column on the right (price increase 4 %) is thus always higher than the one on the left (price increase 2 %).

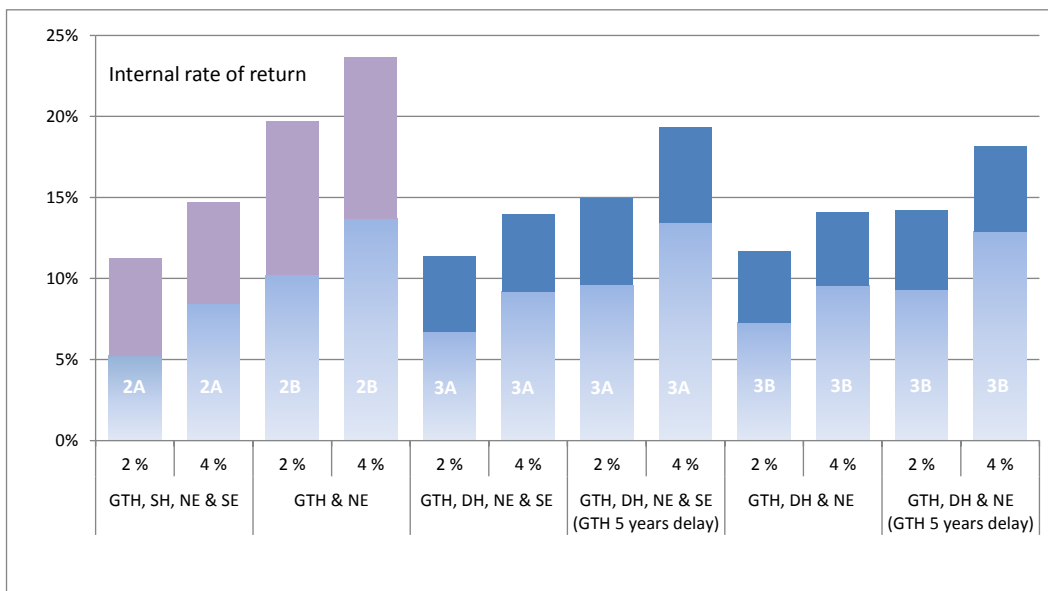


Figure 3. Internal rate of return in the different alternatives. Alternatives 2 and 3 cannot be compared with each other due for example, to different division of investments (for this reason, columns of different colours are also used in the figure). Price range is $\pm 20\%$ (dark part of columns).

The figure also shows that, in alternatives 3A and 3B, the solution implemented after five years leads to a higher internal rate of return. This is explained by both the assumed increase in the price of energy and the assumed decrease in investment costs. In other words, the investment can be made in a more favourable price environment. Thus, the difference between investments made at the present time and after five years is at its largest with the higher assumed increase in the price of energy (4%).

Extending the horizon from 25 years to 50 years will not have a significant impact on the results. There is no impact at all on the payback period, because even the longest payback period is only somewhat over 16 years. The possible residual value (e.g. 50% of the initial investment) as a rule has only a minor impact on the results, because even a 25-year horizon is so far in the future that the net present value is usually very low with these internal rates of return.

5.2 Is it worth choose centralized, decentralized solution or parallel solution?

In figure 4 we can see the total cost comparison. As could be presumed, parallel system is an expensive solution as it is in this case with the 3A and 3B, where district heating is uses as complementary system to geothermal heat. The network electricity however, is the overall cost effective complimentary energy source.

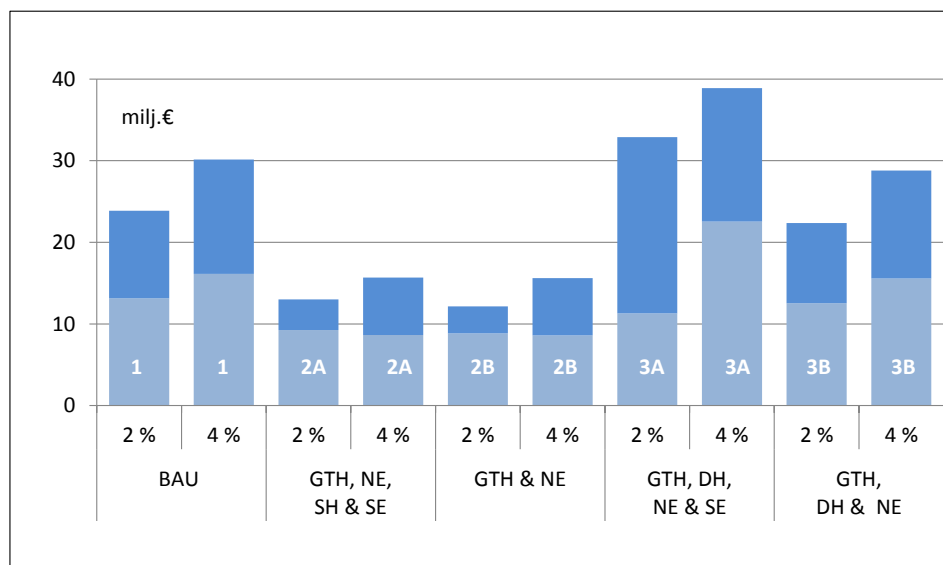


Figure 4. Total costs of energy system alternatives. Reason to high costs of 3A and 3B are a district heating system as complimentary system. Price range is $\pm 20\%$ (dark part of columns).

The calculated payback periods, internal rates of return and total costs are at such a level that solutions based on geothermal heat and network electricity (2A and 2B) would appear to be competitive alternatives. This is in line with other research results made in a similar business environment (Häkämies et al., 2015). In particular, the option 2A but also the option 2B is

surveyed less GHG emissions productive when emissions are calculated by the local factors (figure 1).

Naturally, decisions depend entirely on each operator's required rate of return on the capital and the required payback period. It should be emphasised that these kinds of calculations are very dependent on several different initial assumptions, and even small changes in these assumptions can have a significant impact on the end results. Calculations should, thus, be made using several different parameters, observing their effect on the end results.

The prices and assumptions used in the calculations are largely based on the views of the research scientists and the project participants. No actual offers for these solutions have been requested. The actual prices may differ significantly, particularly due to the conditions in the area, scalability and time of implementation. Conditions in the area in this context refer, for example, to the actual price of geothermal heat depending on the geological conditions in the area. Scalability in this context refers, for example, to there being clearly more information on and estimates for geothermal heat solutions for individual apartment blocks than for an entire residential area. The prices of the technologies are also in a constant flux, and the actual price thus depends on the time of implementation.

6. Discussion

The energy system alternatives appear differently to society, the developers and the future residents of the area. In this case, society is represented by **the city**, ultimately responsible for the built environment and planning as a whole. Energy and climate objectives place binding demands on the city, among other things, in the form of agreements voluntarily made with the state (Energy Efficiency Agreement –site), and image-wise in the form of joint mayoral proclamations. Accolades received in the past also create an obligation. Indeed, from the city's point of view, the best alternative would be the one with the lowest consumption of primary energy and generation of greenhouse gases. The choice would thus be the alternative with as much renewable energy as possible (alternative 2A or 3A). On the other hand, the city owns the district heating company, so it also has grounds for adopting the traditional alternative (1). The traditional alternative is also supported by the fact that renewable energy sources can be utilised in the production of district heat. The utilisation of the existing network and production capacity saves in investment costs and is material-efficient.

It is in the **construction company's** interest to generate profits and avoid risks, as it is bound by a ten-year guarantee on the functionality of the building. By choosing the traditional alternative (1), its investment costs and risks remain lower. On the other hand, it could be in the construction company's interest to profile itself as a frontrunner with ecological values, so the choice could turn to the alternatives involving renewable energy. These alternatives require developing the concept of an apartment block as a product. The traditional concept is that a construction company erects the building; after its completion, the building is managed by a limited liability housing company, supported by energy services that have been centralised to a great extent.

Local energy production would need to be separately organised. This would go against the prevalent development (for example energy efficiency directive 2012/27/EU), as the trend in many technological fields has rather been the opposite, towards centralisation and the benefits of the economies of scale. Based on the Smart City agenda, virtual power plants have been theorised, with this kind of local energy production bundled together and with a common operator. This would be a major regime-level change compared to the current situation.

Living as affordably as possible is in the interests of the **residents**. In this context, self-produced, free energy sounds like a tempting alternative. Indeed, when it comes to the heating of single family houses, the choice is often a property-specific system, even partial generation of one's own electricity, although its life cycle costs are currently higher. This particularly applies to countries where small-scale production of electricity has no public subsidies.

The situation is different for apartment blocks already because in the building skin there is a little space for harvesting solar power. Their choices are not made by individual households, but by the limited liability housing companies made up of individual households. For new buildings, the decisions are made by the construction company for the housing company, because only some or none of the housing company shareholders are known at the time of the decision-making. Once the housing company formed from households has been established, it is too late to influence the solutions. In order to be able to benefit from the affordability of the local production, the housing company must assume some responsibility over the system. This responsibility is, however, often outsourced to a maintenance company and it spends the economic advantage of the households.

With hybrid energy systems, the responsibility refers to, for instance, remote monitoring and the investigation and correction of any deviations detected. At this point, things move from traditional maintenance company operations to digital control rooms, where the economies of scale rule and a new breed of business ecosystems thrive.

7. Summary

The subject of this conference paper is an apartment block area comprising near zero energy buildings. The goal was to study the best way to arrange energy services for the area. The area is transitioning from an industrial area to a high-efficiency residential area.

The alternatives that were studied comprised traditional, centralised energy service, and local energy production in the area, using geothermal heat, solar heat and solar electricity. The calculated payback periods, internal rates of return and total costs are at such a level that solutions based on geothermal heat and network electricity would appear to be competitive alternatives. The solutions are area-specific, and must always be studied on a case-by-case basis.

The decision-making is rife with uncertainties. With regard to new technologies and, in particular, hybrid systems, the question are about the optimal control of the operation of the systems either on building or area level. There are examples where attempts at saving primary

energy have resulted in increased consumption due to the systems not functioning properly. Utilising the benefits in full may require the development of a new business ecosystem.

The choice is also influenced by the prior choices of the target area or the city, or so-called path-dependency, which may also be a positive factor. Keeping with the traditional solution allows benefiting from the prior investments. If the energy efficiency of the city's old building stock is improved, the district heating system will have enough capacity for new customers with minor additional investments. The new area will benefit from the centralised system's investments made in on energy efficiency, renewable energy sources, and fulfilment of customer needs, remote monitoring, and large-scale hybrid solutions, including the combined heating and cooling (CHC) -technology.

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An Indicator-based Approach to Neighbourhood Sustainability Assessment for Urban Renewal Decision-making

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Abstract

Urban renewal, as an opportunity of realizing sustainable development, can resolve numerous problems facing cities. Due to the linkage between sustainability and urban renewal, it is helpful to investigate sustainability in urban renewal context. Although there exists a consensus on the importance of sustainable development, this concept is still ambiguous, which may lead towards a deviated direction. In order to capture a better understanding on sustainability in urban renewal, thus making informed decision-making on sustainable urban renewal, some evaluation tools/methods have been proposed. However, most research focuses on a city scale or a renewal project. Sustainability assessment focusing on neighbourhood renewal is still a rarely touched area. With the aim of supporting decision-making in urban renewal, this paper proposed an indicator-based approach to neighbourhood sustainability assessment. Essential steps in this approach are introduced in detail. A case study on several neighbourhoods of Hong Kong is conducted to apply this indicator-based approach. This paper not only provides a better understanding on neighbourhood sustainability in urban renewal process, but also proposes a method of assessing sustainability of neighbourhood for supporting urban renewal.

Keywords: sustainability assessment, urban renewal, neighbourhood, decision-making

1. Introduction

Urban renewal is regarded as a two-fold sword. It can deliver a positive opportunity for realizing sustainable development and act as an antidote for urban problems (Zheng et al., 2014). There also exists some criticism including fading of local culture, destruction of social network, and segregation. Facing different voices on urban renewal, it is important to integrate the concept of sustainability into urban renewal practice. Although the concept of sustainable is accepted widely, its application in practice is not always favouring (Hunt et al., 2008). To better deliver sustainable urban renewal, it is necessary to conduct urban renewal evaluation, especially when it comes to decision-making. For example, a systematic approach with evaluation criteria on urban competitiveness quality and priority model for urban renewal projects was proposed to facilitate decision makers and developers in Taipei in reviewing urban renewal project selections (Juan et al., 2010). A model for measuring sustainability of urban regeneration at project level was proposed to assist decision-making (Peng et al., 2015). Urban regeneration performance was evaluated based on different categories (the economy and work, resource use, buildings and land use, transport and mobility, and community benefits) (Hemphill et al., 2004a; Hemphill et al., 2004b).

However, most studies on urban renewal evaluation focus on the impacts of urban renewal impacts, which are post-evaluation, minimizing the opportunities of promoting sustainability. It is more beneficial if pre-evaluation is included in urban renewal process. Pre-evaluation before urban renewal is crucial for regional policies (Greig et al., 2010). Only a few studies focusing on pre-assessment for urban renewal decision-making. For example, Ho et al. (2011) developed the Dilapidation Index under the context of Hong Kong to assess the building conditions for identifying potential renewal projects. But the Dilapidation Index only focuses on building conditions at building scale. The index of multiple deprivations, as a national matrix in the UK, is also for assessing the need for regeneration activities (Greig et al., 2010). This index is comparatively more comprehensive, yet its local context is in the UK.

Therefore, this research aims at proposing a universally indicator-based approach for sustainability assessment at neighbourhood scale for urban renewal decision-making. Four major steps are involved in the application of this approach. To better illustrate it, a case study on eight neighbourhoods of Hong Kong is employed to examine this indicator-based approach. The second section reviews previous work on neighborhood sustainability assessment and urban renewal assessment. The following section presents the conceptual framework of this approach. In further unravelling this approach, the fourth part shows the case study. The fifth section discusses limitations of this paper. And the final section concludes this paper.

2. Relevant Work

2.1 Neighborhood sustainability assessment

Sustainability has been an essential objective in city development. After it was firstly proposed in the Brundtland Report, it has been considered as a crucial issue for urban development. In order to

transit to sustainable urban development, it is necessary to know where we are, what goals that we have met, and what to do next. This poses challenges and potentials on sustainability assessment. Devuyst et al. (2001) provided a definition of sustainability assessment: “a tool that can help decision-makers and policy-makers decide which actions they should or should not take in an attempt to make society more sustainable.” Sustainability assessment is useful for decision-makers on determining which actions should or should not be taken for realizing sustainable development (Ness et al., 2007).

There are some internationally well-known tools for sustainability assessment for neighbourhood, including but not limited to the following ones: Building Research Establishment’s Environmental Assessment Method Communities (BREEAM Communities), CASBEE for Urban Development, The Leadership in Energy and Environmental Design for Neighbourhood Development (LEED for Neighbourhood Development). Comprehensive Assessment System for Building Environmental Efficiency for Urban Development (CASBEE for Urban Development) addresses the assessment of urban areas by focusing on the phenomena of aggregation of buildings and the outdoor spaces (Haapio, 2012). BREEAM Communities focuses on the planning stage of the development process of large-scale project with the aim of making the project show their environmental, social and economic benefits to the local community (BREEAM, 2009). LEED for Neighbourhood Developments was established as a U.S. national standard for neighbourhood design which focuses on green building and smart growth. It aims at assessing the impacts of development projects based on its standards (USGBC, 2006). Although different tools have different emphases and criteria, themes applied by most tools are involved with several aspects: resources and environment, transportation, economic, location, site selection pattern and design, and innovation (Sharifi and Murayama, 2013). Through analysis of existing systems of neighbourhood sustainability assessment, locality (e.g. local culture and laws) is emphasized as a necessary aspect for adaptability of existing systems (Berardi, 2013).

2.2 Urban renewal evaluation

The importance of evaluating urban renewal/regeneration initiatives on monitoring current renewal/regeneration programs has been widely acknowledged (e.g. Peng et al., 2015; Kauko, 2012; Hemphill et al., 2004a; Hemphill et al., 2004b). A large number of studies have been conducted in terms of urban renewal/regeneration impacts.

Some research only focuses on one certain aspect of impacts of urban renewal, like social or economic impact. For example, in order to identify social impacts of urban waterfront regeneration in Helsinki, four themes of social impacts (resources and identity, social status, access and activities and waterfront experience) were proposed (Sairinen and Kumpulainen, 2006). From economic perspective, the impacts of a public-sector-led urban renewal project on housing prices in Hong Kong were measured by a price gradient analysis (Lai et al., 2007). Some researchers explore several aspects together. Social and economic impacts of residential brownfield development in the most deprived urban neighbourhood were assessed in terms of changing housing market, residential density, population growth and economic deprivation (Bäing and Wong, 2012).

There are also studies comprehensively evaluating urban renewal initiatives. Impacts of urban renewal on socio-economic and spatial structure are often discussed together (e.g. Uzun, 2003; He and Wu, 2007; Wu and He, 2005), although different studies may use various indicators. Some scholars apply composite indicators to assess urban renewal comprehensively (Hemphill et al., 2004a; Hemphill et al., 2004b; Hunt et al., 2008; Pérez and Rey, 2013; Wedding and Crawford-Brown, 2007). To measure regeneration performance, a group of indicators under different categories (the economy and work, resource use, buildings and land use, transport and mobility, and community benefits) were proposed (Hemphill et al., 2004a; Hemphill et al., 2004b). While most studies assess urban renewal from the perspective of post-evaluation, only a few address pre-evaluation. To facilitate regeneration decision-making in Birmingham Eastside, Hunt et al. (2008) presented a series of indicators including social aspect (user comfort, form and space, access, amenity, inclusion), economic aspect (social benefits and cost, transport, employment, competition effects, viability), environmental aspect (air quality, land use, water, ecology and cultural heritage, design and operation, transport), and natural resources (materials, water, energy, land utilization, waste hierarchy).

3. Conceptual Framework

This research develops an indicator-based approach to neighbourhood sustainability assessment with the purpose of providing references for urban renewal decision-making. Figure 1 shows the conceptual framework. There are totally four steps, in which different methods could be applied. This section is to provide details in each step.

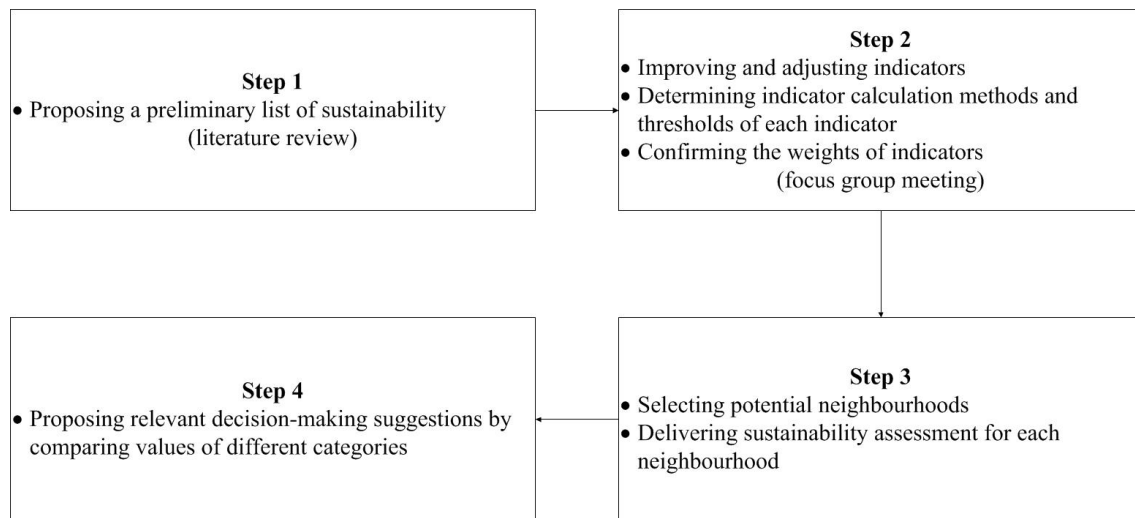


Figure 1: Major steps in the proposed approach

3.1 Step One

Various indicators have been applied in studies on sustainability assessment at neighbourhood scale. The existing tools or research can be useful resources for identifying initial indicators and their

calculation methods. During this process, two other aspects need to be considered. One is the local condition. Another is what is crucial for urban renewal. In summary, the initial indicator list is a comprehensive indicator system which integrates sustainability consideration, urban renewal focus, and local conditions. Different indicators should be categorized into different themes. A hierarchy framework of indicators then can be drawn. Figure 2 shows the hierarchy framework of indicators.

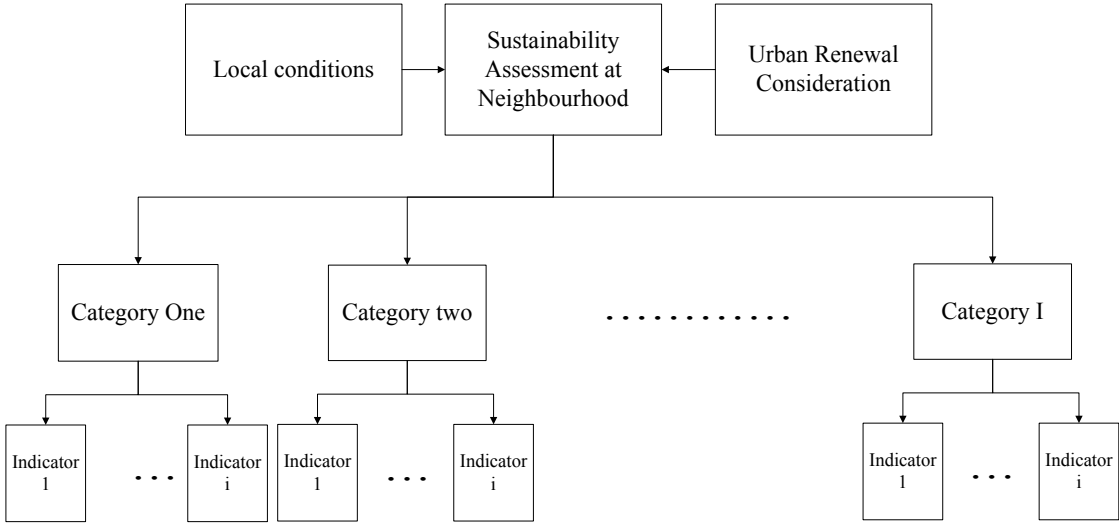


Figure 2: The hierarchy framework of indicators

3.2 Step Two

The selected indicators may be subjective, thus requiring adjustment of indicators. Focus group meeting is conducted to collect suggestions on existing indicators and to add ignored indicators selected during step one. After adjusting and improving the indicator list, it is necessary to determine calculation methods and thresholds of each indicator.

Under each category, weights of indicators is to be determined. There are different ways. For example, participants can pose specific weights for various indicators directly after discussion. Or participants judge the relative importance of each indicator, the results of which are then to be used for calculating weights by methods like analytic hierarchy process (AHP) and analytic network process (ANP). The sum of weights for indicators in each category should be 1.

3.3 Step Three

Potential neighbourhoods for renewal decision-making are to be determined during this step. Then relevant data is to be collected accordingly. The following actions include calculating values of each indicator and then obtaining the final value of each category.

Each indicator has its unique calculation method. The initial evaluation results of indicators are obtained by using different units and cannot be compared directly, thus requiring standardization before calculating values of different categories. Taking into account of the positive and negative

effects of different indicators on sustainability, two formulas were applied for standardization (Pirrone et al., 2005).

$$\text{Positive indicator: } y_{ij} = (x_{ij} - \min x_{ij}) / (\max x_{ij} - \min x_{ij}) \quad (1 \leq i \leq m, 1 \leq j \leq n) \quad (1)$$

$$\text{Negative indicator: } y_{ij} = (\max x_{ij} - x_{ij}) / (\max x_{ij} - \min x_{ij}) \quad (1 \leq i \leq m, 1 \leq j \leq n) \quad (2)$$

The final value of each category is calculated by the formula below, in which S_I stands for the final value of category I, v_i represents value of indicator i, and w_i is the weight of indicator i.

$$S_I = \sum_i^i v_i w_i \quad (3)$$

3.4 Step Four

After obtaining values of various categories, relevant suggestions on urban renewal decisions can be proposed accordingly. This approach does not suggest calculating a total score of sustainability, but tends to compare each category among neighbourhoods, which can offer more detailed and specific strategies for neighbourhood renewal.

4. Case Study

4.1 Study Area and Data Preparation

Hong Kong is selected as the case study context because of its unique characteristics. Firstly, it is now facing serious urban decaying problems with approximate 4,000 buildings aged 50 years or above. Secondly, it is a typical high-density city in Asia, which experiences overcrowding and scarcity of land supply. Urban renewal can free some land for Hong Kong. Thirdly, various voices emerge in urban renewal process of Hong Kong, within which there are also some criticism such as profit-driven, fading of local culture and destruction of local network.

Eight tertiary planning units TPUs in Kowloon District of Hong Kong are selected in the case study to experiment the proposed approach (See figure 3). These TPUs, are applied by Planning Department of Hong Kong for planning purpose. A database for this research is prepared, in which both spatial and non-spatial data are included. Spatial data include land use map, road network map, the location of public facilities, and building distribution. Non-spatial data involves environmental and social aspects. The data is from different governmental departments, including Planning Department, Lands Department, Building department, Hong Kong Housing Society, Environmental Protection Department, and Census and Statistics Department. Data processing actions involve digitalizing land use map and integrating data from different sources in ArcGIS software package.

The Location of Tertiary Planning Units

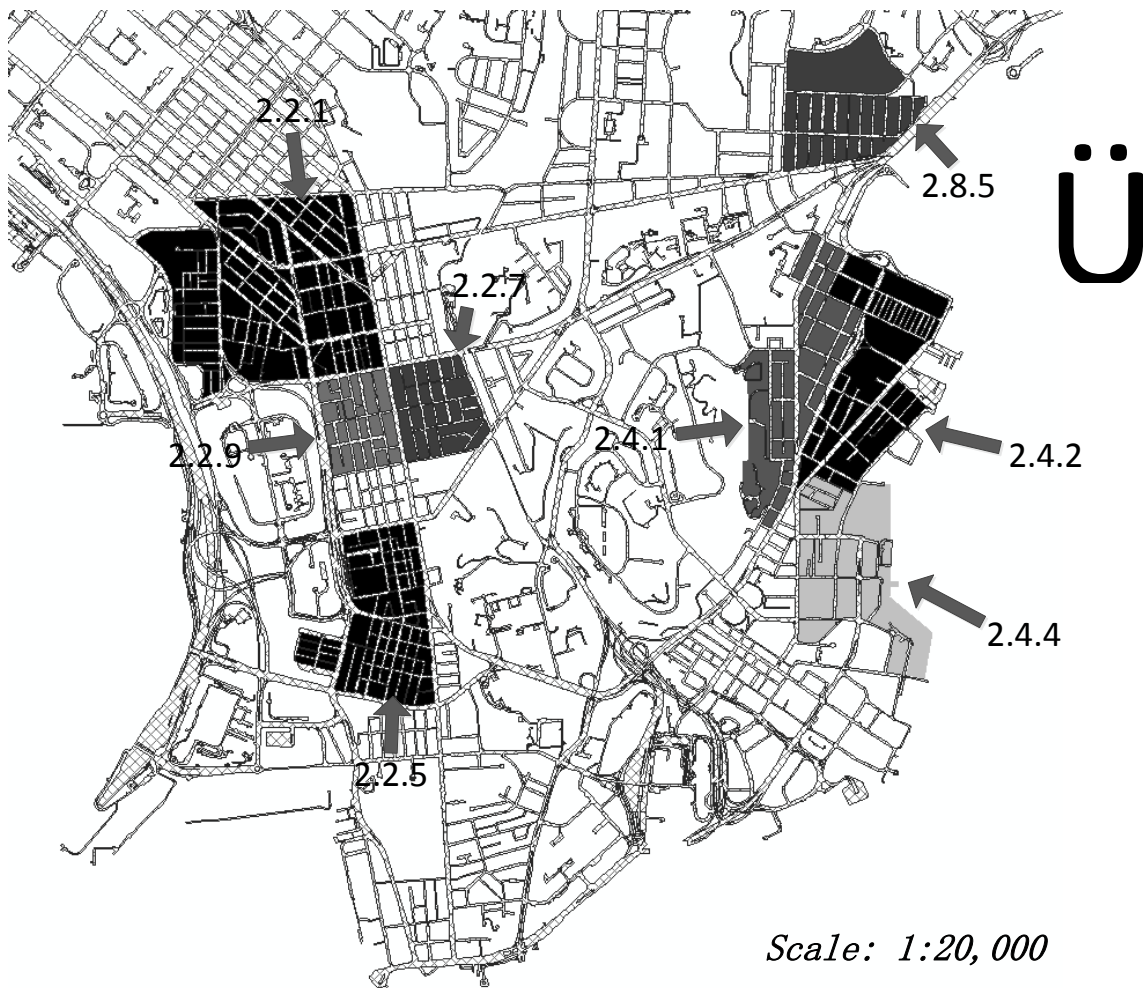


Figure 3: The location of tertiary planning units (TPUs)

4.2 Application of the proposed approach

Following the steps in the conceptual framework, the proposed approach was applied. Through literature review (e.g. Greig et al., 2010; Hemphill et al., 2004a; Hemphill et al., 2004b; Hunt et al., 2008; Boyko et al., 2012; Cheng and Lin, 2011), an initial list of indicators were proposed. This case categorized indicators into five themes, which are social aspect, environment and resources, economy and work, land use form and building conditions. Then in step two, two more indicators (Density of Small businesses with local characteristics and the fragment level of property rights) were added and calculation methods were confirmed for each indicator. To make it simple (because this study is a pilot one), each indicator is regarded contributing the same to the total value of each category; thus, the weights for indicators are the same. Several indicators were not included in the calculation because of lacking data at this scale. Additionally, this is a pilot study for illustrating this approach, it is acceptable that several indicators are not included. Table 1 presents an adjusted

indicator list, which can also be referred by other contexts. Table 2 shows the final scores of different categories. Figure 2 can clearly show the comparing results in space.

Base on the results, performance of each neighbourhood can be compared directly. In terms of social aspect, TPU 2.2.1 performs the best while TPU 2.4.1 has the lowest value. As for economy and work, TPU 2.4.4 stands out with its highest value while other TPUs have similarly low values. TPU 2.2.7 obtains the highest value for the performance of environment and resources. TUP 2.2.9 shows the best result for land use form while land use form of TPU 2.2.1 presents the worst one. Building conditions in both TPU 2.2.1 and TPU 2.2.7 are satisfactory and TPU 2.8.5 presents the most serious building condition.

From these results, some issues could be found. Although some TPUs perform well in certain aspects, they may face some problems in other aspects. This phenomena reminds of a fact that values of some positive aspects may offset those negatives ones if we only refer to the overall value of sustainability. Therefore, calculating different categories respectively can avoid this dilemma in this approach. Based on the results, corresponding strategies can be proposed for each neighbourhood. For example, for TPU 2.8.5 with higher value in land use form and comparatively lower values in other categories, building rehabilitation initiatives are urgent. Then for some decaying area, comprehensive redevelopment may be an alternative for addressing various problems. It is essential to include both physical and socio-economic improvement during renewal.

Table 1: A summary of indicators and their measurement

<i>Category</i>	<i>Indicator</i>	<i>Measurement</i>	<i>Remarks</i>
<i>Social aspect</i>	<i>Human density</i>	<i>Population/Area of the planning unit</i>	<i>Results can be obtained through normal calculation</i>
<i>Social aspect</i>	<i>Age diversity</i>	$\frac{1}{cat} \sum_{i=1}^{cat} \left(1 - \frac{n_{cat_age_i}}{n_{cat_age_i}^{obj}}\right)^2$	<i>cat is the number of different age groups, $n_{cat_age_i}$ is the population belonging to age group i, $n_{cat_age_i}^{obj}$ refers to the objective population in age group i</i>
<i>Social aspect</i>	<i>Residential floor area per capita</i>	<i>Residential floor area/Population</i>	<i>Results can be obtained through normal calculation</i>
<i>Social aspect</i>	<i>Public transport diversity</i>	$\frac{1}{cat} \sum_{i=1}^{cat} \left(1 - \frac{n_{cat_trans_i}}{n_{cat_trans_i}^{obj}}\right)^2$	<i>cat means the number of public transportation types, $n_{cat_trans_i}$ is the number of transportation points (stops/stations) in type i, $n_{cat_trans_i}^{obj}$ is the objective number of transportation points in type i.</i>
<i>Social aspect</i>	<i>Facilities diversity</i>	$\frac{1}{cat} \sum_{i=1}^{cat} \left(1 - \frac{n_{cat_faci_i}}{n_{cat_faci_i}^{obj}}\right)^2$	<i>cat represents the number of facility types, $n_{cat_faci_i}$ is the number of facility i, $n_{cat_faci_i}^{obj}$ is the objective</i>

			<i>number of facility i .</i>
<i>Economy and work</i>	<i>Labor force participation rate</i>	<i>Labor force participation rate</i>	<i>Data can be obtained from statistical information</i>
<i>Economy and work</i>	<i>Disposable income per capita</i>	<i>Disposable income per capita</i>	<i>Data can be obtained from statistical information</i>
<i>Economy and work</i>	<i>Diversity of business activities</i>	$\frac{1}{cat} \sum_{i=1}^{cat} \left(1 - \frac{n_{cat_busi_i}}{n_{cat_busi_i}^{obj}}\right)^2$	<i>cat is the number of various business groups, $n_{cat_busi_i}$ is the population belonging to business category i, $n_{cat_busi_i}^{obj}$ refers to the objective population in business category i</i>
<i>Economy and work</i>	<i>Density of Small businesses with local characteristics</i>	<i>The trade of small business with local characteristics/the area of planning unit</i>	<i>Data cannot be obtained; This is a newly added indicator</i>
<i>Resources and environment</i>	<i>Waste generation</i>	<i>Total waste generation/population</i>	<i>Data can be estimated</i>
<i>Resources and environment</i>	<i>Waste recycling</i>	<i>Number of waste recycling facilities/area the planning unit</i>	<i>Data can be estimated</i>
<i>Resources and environment</i>	<i>Electricity consumption</i>	<i>Total electricity consumption/population</i>	<i>Data cannot be obtained</i>
<i>Resources and environment</i>	<i>Air quality</i>	<i>Air quality index</i>	<i>Data cannot be obtained</i>
<i>Resources and environment</i>	<i>Water consumption</i>	<i>Total water consumption/population</i>	<i>Data cannot be obtained</i>
<i>Land use form</i>	<i>Land use mix</i>	$-\sum_{i=1}^n l_i \ln l_i / \ln n$	<i>l_i is the area of land use type i, n means the number of land use types.</i>
<i>Land use form</i>	<i>Accessibility to cultural facilities</i>	<i>Number of cultural facilities within 300 meters</i>	<i>Results can be obtained through spatial analysis in GIS</i>
<i>Land use form</i>	<i>Accessibility to education services</i>	<i>Number of education facilities within 300 meters</i>	<i>Results can be obtained through spatial analysis in GIS</i>
<i>Land use form</i>	<i>Accessibility to health care services</i>	<i>Number of health care facilities within 300 meters</i>	<i>Results can be obtained through spatial analysis in GIS</i>
<i>Land use form</i>	<i>Accessibility to sport and leisure facilities</i>	<i>Number of sport and leisure facilities within 300 meters</i>	<i>Results can be obtained through spatial analysis in GIS</i>
<i>Land use form</i>	<i>Accessibility to other facilities</i>	<i>Number of other facilities within 300 meters</i>	<i>Results can be obtained through spatial analysis in GIS</i>

<i>Land use form</i>	<i>Accessibility to public transport</i>	<i>Number of public transport points within 300 meters</i>	<i>Results can be obtained through spatial analysis in GIS</i>
<i>Land use form</i>	<i>Open space coverage ratio</i>	<i>Area of open space/Area of the planning unit</i>	<i>Results can be obtained through spatial analysis in GIS</i>
<i>Building condition</i>	<i>Average building age</i>	$\sum_i^n age_i / n$	<i>Results can be obtained through normal calculation</i>
<i>Building condition</i>	<i>Number of buildings aged 50 years or above</i>	<i>Number of buildings aged above 50 years</i>	<i>Data can be obtained directly from statistics</i>
<i>Building condition</i>	<i>Building maintenance</i>	<i>Number of building repair cases/Number of buildings aged above 50 years</i>	<i>Data can be obtained through normal calculation</i>
<i>Building condition</i>	<i>Building density</i>	<i>Floor area/Area of the planning unit</i>	<i>Data can be obtained through normal calculation</i>
<i>Building condition</i>	<i>The fragment level of property rights</i>	<i>The fragment level of property rights</i>	<i>Data cannot be obtained; This is a newly added indicator</i>

Table 2: Values of neighbourhoods in different categories

	<i>Social aspect</i>	<i>Economy and work</i>	<i>Environment and resources</i>	<i>Land use form</i>	<i>Building condition</i>
2.2.1	0.618491	0.261551	0.532039	0.231615	0.503037
2.2.5	0.38292	0.26032	0.537261	0.355585	0.353346
2.2.7	0.495204	0.175815	0.899771	0.513832	0.57359
2.2.9	0.569303	0.135118	0.720754	0.60348	0.496879
2.4.1	0.323248	0.236482	0.638122	0.268797	0.465472
2.4.2	0.419863	0.197809	0.590737	0.432339	0.306757
2.4.4	0.501843	0.600275	0.440865	0.505447	0.390898
2.8.5	0.387836	0.242227	0.396396	0.621737	0.286446

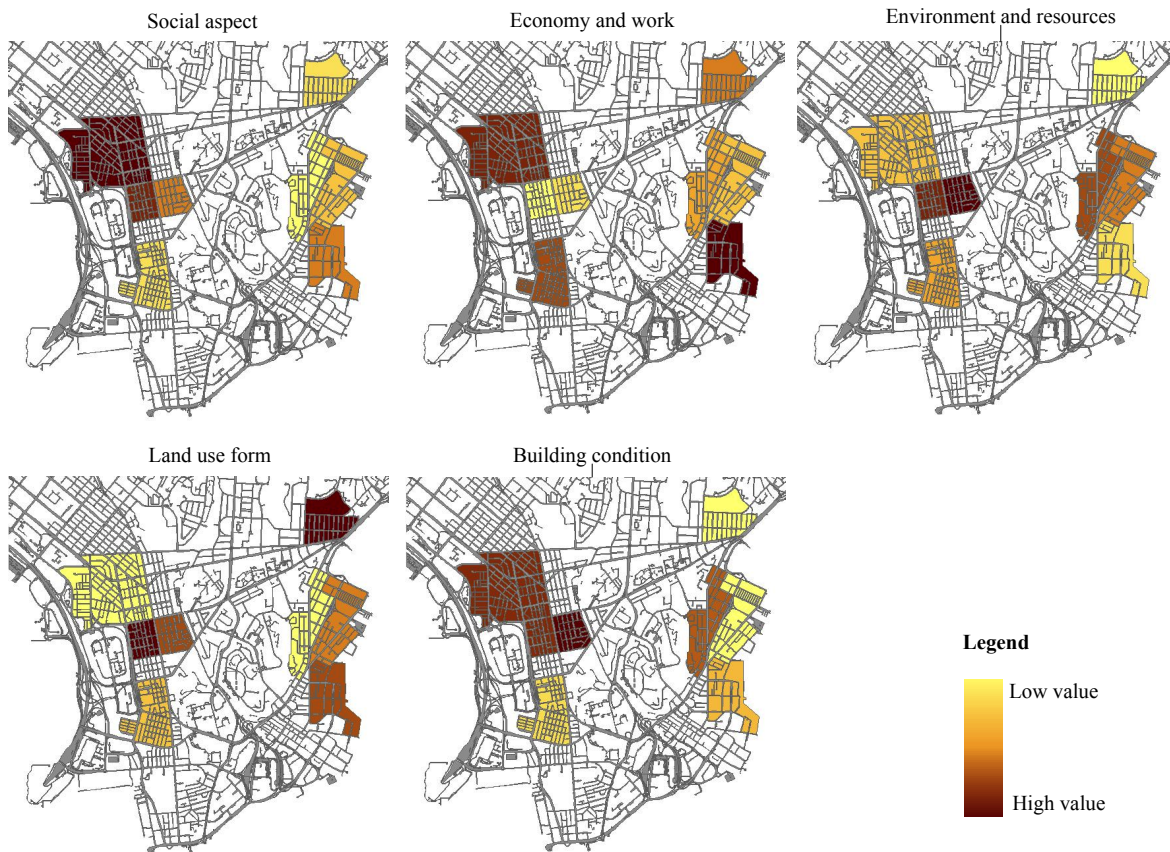


Figure 4: Comparison of values for different categories

5. Discussion

This paper proposed an indicator-based approach to assessing neighborhood sustainability for better urban renewal decision-making. Four steps are included in the assessment. Case study facilitates illustrating how to apply this approach in practice. This approach could be applied in different contexts but be adjusted based on specific conditions. The indicator list proposed on the basis of Hong Kong context can also be referred by other studies. Changes are suggested if necessary because different contexts face different challenges and issues in neighborhood renewal.

This research has some limitations. Due to data limitation, some calculation results are estimated, which may not be accurate. And data of several indicators cannot be obtained at this scale, thus ignoring their effects on the final results. Another limitation is that weights were not developed in step two. In order to further improve it, it is suggested to include as much data as possible. It would be of great use if the weights of various indicators were obtained in step two. This approach is not aiming at making decisions directly, but to provide useful references for decision-makers. Therefore, decision-makers should combine other information and approaches when applying this approach.

6. Conclusions

With the aim of supporting urban renewal decision-making at neighbourhood scale, this paper presents an indicator-based approach for neighbourhood sustainability assessment. This approach involves four essential steps, which are illustrated in the case study. It has several shining points. Firstly, unlike some studies on assessing urban renewal, it requires a more comprehensive perspective for indicator selection, which suggests sustainability, urban renewal and local context. Secondly, its focus is neighbourhood scale, which is a proper scale for initiating urban renewal activities. This scale is regarded as an important geographic and social unit for practicing planning activities (Rohe, 2009). Thirdly, with the fact that most studies on urban renewal evaluation focus on impacts of urban renewal (post-evaluation), the pre-assessment by this approach maximizes the opportunities of applying sustainability into renewal practice. The proposed approach can benefit both theory and practice.

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Institutional Development is the Key for Sustainable Water Services in the Built Environment

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Abstract

This paper explores the role of institutions in the development of water services – especially community water supply and wastewater. It is based on an extensive research programme on the evolution of water services in Finland that also compares our domestic development with international achievements since WWII.

The term *institution* is here used to mean the “rules of the game” while the term *organisation* is used to mean any of the “players”. Institutions include both formal and informal rules, and often a large part of the latter are unseen. The paper deploys a wider view of technology development: (i) artefacts, (ii) processes, and (iii) knowledge how to apply (i) and (ii). It reminds of appropriate technology where we need a variety of criteria for technical, social, and economic appropriateness.

Water services are under continuous need of reassessment. Some changes may seem more dramatic short-term than in the longer term. Yet, they are relative and depend on the time scale used: operational (1 year), strategic (1–10 years) or visionary (20–50 years). Due to path dependence, major strategic decisions may even have an impact lasting over a century – to the futures and to the pasts.

The development paths have hardly ever been linear; on the contrary, the paths have usually divided into new development paths. In some cases, like when selecting a new raw water source, older paths may have been rediscovered. The driving forces seem to be linked to legislation and especially to water pollution control. Instead of dramatic ad-hoc reforms, overall water services evolution in Finland has mainly been based on the principle of continuous development.

In the future, we need to pay worldwide more attention to institutions as well as to management, institutional, policy, and governance issues, including the challenges of pricing and asset management of water services infrastructures.

Keywords: sustainability, institutions, path dependence, pasts, futures

1. Introduction

Water and wastewater systems are of fundamental importance to the development of communities and the welfare of people and nature. Water services – here mainly community water supply and wastewater services – will face huge challenges in the coming decades in Finland, Europe, and the rest of the world. If the current trend continues without major improvements, up to two thirds of mankind will suffer from chronic water scarcity and/or polluted water in 2050. In spite of its problems and challenges, Finland has been among the top countries in many international comparisons of water and environment management. The rapid structural change of society has also been reflected on our water services. A key challenge is to increase the weight of the invisible water services and systems in societal decision-making.

While there is a huge demand for further investments in water and sanitation systems worldwide, it is an even bigger challenge to improve the efficiency and functioning of the current systems. In both cases proper institutions, or rules of the game, are required.

Water services are managed and governed at lower levels and scale than water resources. As concerns the wider role of water in development, the International Law Association (2004) pointed out that water and wastewater services are *vital human needs* of communities. In other words, they are the most important purpose of water use (Katko and Rajala 2005). At least in the western world, water services, a fundamental, yet mostly invisible part of the community infrastructure, are taken for granted, assuming that they are available 24/7. As Golder et al. (2013) pointed out, water is one of the most taken-for-granted aspects of daily life. Yet, in most cases in developing economies, intermittent water services pose severe challenges for citizens, especially the poor.

Unfortunately, many developing and transition economies still lack water service systems, or they are inoperational, or provide service only for a few hours a day and cannot therefore be taken for granted. The World Water Development Report 2003 highlighted this major problem as follows: “Sadly, the tragedy of the water crisis is not simply a result of lack of water but, essentially, one of poor water governance” (UNESCO 2003). Accordingly, OECD (2015) reminds that “managing and securing access to water for all is not only a question of money, but equally a matter of good governance”. Thus, there is an urgent need to assess recent experiences, identify good practices, and develop practical tools for assisting different levels of governments and other stakeholders for more effective, fair, and sustainable water policies.

2. Methods and approaches

This paper is based on cumulative experiences of a variety of studies by the Capacity Development in Water and Environmental Services research team at Tampere University of Technology (TUT) since 2000. The paper builds on material and research conducted by the author and the research team in some 80 research projects, 10 doctoral dissertations, and 25 MSc theses. The paper aims to explore the role and significance of institutions and their development within the overall development of water services. The paper is largely based on a project analysing the major findings on water services development within its wider institutional

context after WWII and especially during the last decades, including implications for the futures. This study (Katko 2016) has been supported by several foundations and the Academy of Finland (no. 288153) which is highly acknowledged.

In this context of water services organisations, the definition of *institutions* by D.C. North, a Nobel Laureate in Economics, is here applied. He used the football (soccer) analogy and defined institutions as the “rules of the game” while organisations are the “players” (North 1990). The rules differ in size and shape. This New Institutional Economics (NIE) calls into question many ideas of the more classical schools of thought.

Andrews (2013) uses the iceberg metaphor for reminding that “a large part of institutional logic is unseen or below the water line because it is informal”. He further reminds that institutional reforms can only work if they are tailored to the local context and therefore the so-called best-practice reforms tend to fail. Whereas, for instance, the World Bank links “institutional context” typically to laws and other regulations, Scott (cited by Andrews, 2013, 43) points out that institutions include regulative, normative, and cultural-cognitive elements.

Based on a sustained institutional framework, a distinction between service *provision* and *production* should be also made, as articulated by Ostrom (1990, 31) and Oakerson (1999). This distinction is important since in most countries such as Finland legislation puts municipalities in charge of providing or arranging the services, whereas services are produced or implemented by utilities or cooperatives. Yet, professional literature seldom recognises this fundamental difference (Katko and Hukka 2015).

Another key definition refers to the concept of *technology*. Here, technology is considered in a wider context which covers (i) technological artefacts, (ii) procedures, and (iii) knowledge required how to apply both (i) and (ii) (Leppälä 1998). A somewhat similar definition was presented by Jacob Bigelow (cited by Hughes 2004, 2–3) already in 1831 when he stated that “technology involved not only artefacts but also the processes that bring them into being”.

Hughes (2004) further pointed out that technology is not limited to technological practices – often considered engineering – but ought to include also the processes that bring technology into being, namely invention and human ingenuity. Regarding engineering sciences, Naukkarinen (2015) identified five categories of doctoral dissertations at TUT: experimental design science, mathematical design science, naturalistic design science, explanatory inquiry, and interpretive inquiry. The categories may also overlap and they do not necessarily follow any faculty borders, showing the diversity of engineering sciences and technology development. Hukka et al. (2007) addressed the need for methodological and even philosophical diversity in water management since a single approach cannot answer to all of the research needs, and the fact that a bias in favor of a single research approach may prevent finding adequate answers to wider governance issues. Indeed, it is possible to create most valuable findings in areas that are between various disciplines.

In the late 1970s, Pacey (1977) discussed the dimensions of *appropriate technology*, and concluded that technology alone is not enough, but in addition we need a variety of criteria for

technical, social, and economic appropriateness. In order to discuss technologies Pacey (1983) also introduced two major spheres: *user sphere* and *experts sphere* and argued that “good technology” should take advantage of both of these major spheres. Futures researchers have pointed out the *evolutionary nature of development*. This means that development and technology are not deterministic, but at certain points we will face bifurcation or turning points (Mannermaa 1991).

The relationships between the empirical data collected from the real world and the various theories used in this research programme and by the wider CADWES team are shown in Figure 1. Empirical data from the real world are to be tested by various methods, often according to the so-called PESTEL framework which categorizes environmental influences into six main types: political, economic, societal, technological, environmental, and legislative. The PESTEL framework has proved useful since it forces one to assess development in a wider institutional and socio-economic framework.

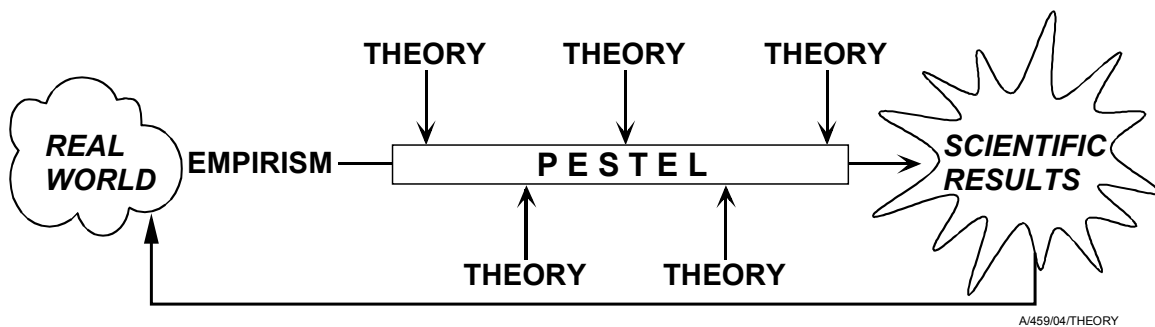


Figure 1: The major approach of the programme: relations between real word, empirism, research theories, and scientific results (Eskola 2001, 138; modified by the author)

3. Major Frameworks for Institutional Development

Water services in Finland are provided and produced at least at four different levels through various modes: from on-site to cooperatives, municipal utilities, and various types of inter- and supramunicipal arrangements (Table 1). These four levels are often connected to each other by various means. Municipal utilities are under public law whereas cooperatives are private. This diversity and multi-level governance describes both organisations and institutions. For some it may seem fragmented but in the Finnish conditions this “insdiversity” – different ways of providing services – gives flexibility to operate case by case based on local conditions. This is not to understate the challenges that they also have. In any case, the overall development is to take into account the connections between the various levels, bearing in mind the poem by Limerick (2012): “Rural and urban places, Are tangled together like laces. They’re like sister and brother, They have never been opposite cases”.

As articulated by Ostrom (1990, 31) and Oakerson (1999), a distinction between service provision and production should be, however, made. This distinction is a major concern in most countries where legislation often puts municipalities in charge of providing or arranging the services which are produced and implemented by utilities. This distinction goes undetected by

almost all parties involved and literature generally uses only the term “provision” without explaining its more accurate meaning.

Table 1. Four key levels of water services in Finland with their key characters (Katko 2016 forthcoming)

<i>Level</i>	<i>Features</i>	<i>No. of systems</i>	<i>Population served (%)</i>
<i>On-site systems</i>	<i>Dispersed rural areas</i>	<i>many</i>	<i>10</i>
<i>Water Users Associations</i>	<i>Villages and towns</i>	<i>1400</i>	<i>5*</i>
<i>Urban water and wastewater undertakings</i>	<i>Water and wastewater often merged</i>	<i>300</i>	<i>50</i>
<i>Inter- and supra-municipal systems</i>	<i>Inter-municipal agreements</i>	<i>many**</i>	<i>n.a.</i>
	<i>Wholesale water</i>	<i>24</i>	<i>n.a.</i>
	<i>Wholesale wastewater</i>	<i>12</i>	<i>n.a.</i>
	<i>Regional water and wastewater companies***</i>	<i>3</i>	<i>28</i>

* some 20 in large villages and towns

** some continuous, some as reserve

*** 2 stakehold companies owned by municipalities, 1 federation

n.a. not available

Through mere legislation and requirements, water services have many stakeholders and interest groups (Figure 2). Water entities at various levels produce services that in Finland are arranged by municipalities except for small and on-site systems. In fact, globally municipalities or other public authorities are owners of some 90 percent of water utilities, 95 percent of wastewater systems, and likely close to 100 percent of stormwater systems. Water utility board members are elected officials. Likely the core resource of any utility is competent personnel. Activities require economic resources obtained, ideally, by charges from customers – such as the case is in Finland – rather than through taxation. Local administration supervises the actions through regulations. The State and the European Union are in charge of legislation, policy, and regulation that are controlled by regional authorities.

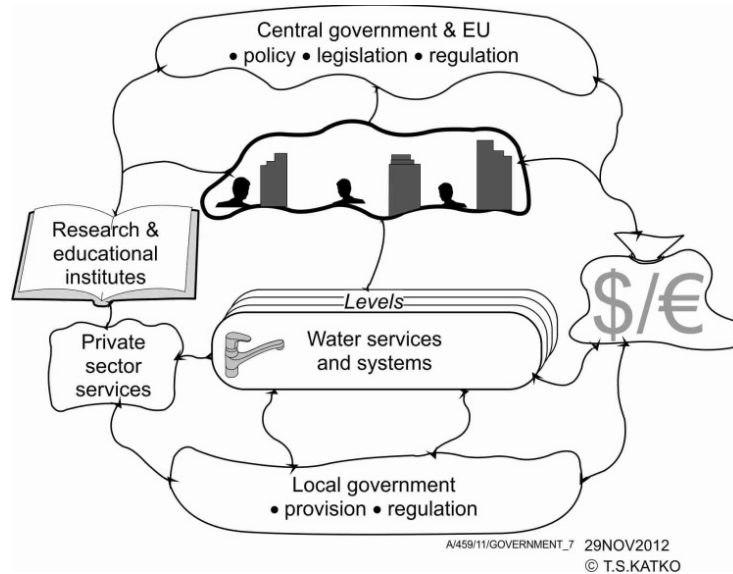


Figure 2: Overall Cooperation Framework of Water Services and systems: major stakeholders and their relationships (Katko, forthcoming 2016)

Water utilities buy services from the private sector as they have done since the beginning of the water systems (Juuti and Katko 2005). For the purposes of this study, we call this *public-private cooperation* instead of *partnership* that has been misleadingly used for the promotion of multinational companies and their long-term contracts, thus in practice reducing competition (Hukka and Katko 2003). Educational and research institutes create the basis for competences and human resources. As for lobbying for water services, the Finnish Water Utilities Association and the Association of Finnish Water Cooperatives are major actors. In addition, we have other direct or indirect stakeholders, which have their own specific roles. These include, e.g., health authorities, water protection associations, and regional councils. In any case, it is essential for each of the stakeholders to have a role that fits to the totality in the most appropriate way.

Another major feature of water services management is related to time. Nowadays futures and strategic thinking is used in many sectors for identifying and having influence on the development of services. The former “prediction” by futurologists has been replaced by futures research and forecasting that rather tend to have active influence on preferable futures and development paths. (Bell 1997) Yet, it is good to remember the argument by George Santayana (1863–1952) “those who cannot remember the past are condemned to repeat it”.

Water services’ futures can be explored through three different timeframes (Figure 3): operative daily actions (one year), strategic thinking (5–10 years), and visionary leadership (10–50 years). The thinner the rectangle, the less time is generally spent on it. The core of visionary thinking is that a sector or organisation tries to identify a state of futures which seems most preferable. Thereafter, from this visionary state, alternative development paths and strategies will be explored for reaching the identified state. Due to path dependence, major strategic decisions may even have an impact lasting over a century – to the futures and to the pasts (Kaivo-oja et al. 2004). Sometimes the argument “we are not interested in history, we are interested in the futures” is actually presented seriously. However, history and futures do not exclude each other. This misconception is mainly due to the path dependence of water services infrastructure development (Melosi 2000); certain strategic decisions have unavoidable long-term impacts.

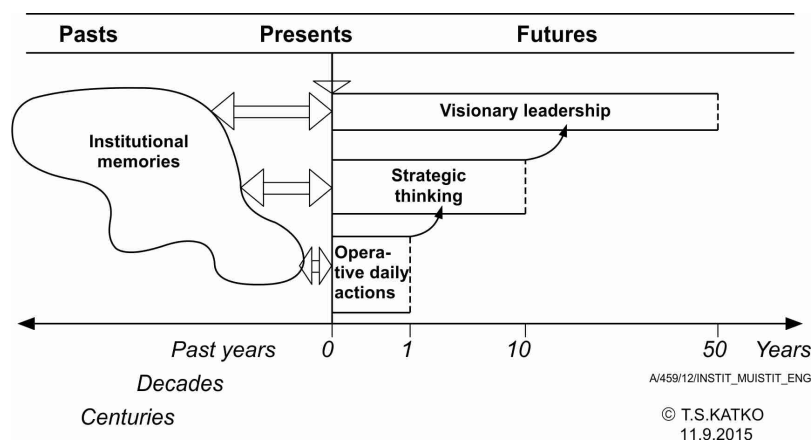


Figure 3: Timeframe for futures thinking and leadership: from operational to strategic and visionary thinking (Katko, forthcoming 2016)

At least in Finland, the selected major paths have hardly ever been linear; on the contrary, the paths have usually divided into new development paths. In some cases, such as selecting a new raw water source, older paths may have been rediscovered. The driving forces seem to be linked to legislation – especially to the requirements of water pollution control (Katko et al. 2006).

Water services are under continuous need of reassessment. In the short-term some of the changes may seem dramatic, but they are not necessarily so in the longer term. Such changes are anyhow relative and depend on the viewpoint and timeframe (Figure 4). In fact, the timeframe of water services development is exceptionally long, up to 125 years to the pasts and 125 years to the futures. Therefore, instead of one year “the quarter of water services” needs to be counted from a millennium, a fundamentally different timeframe. By no means is this to deny that daily operations are to be managed as well as possible; they should not be ignored.

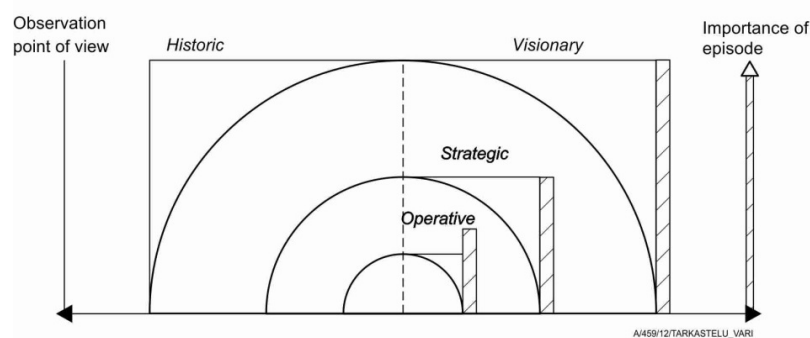
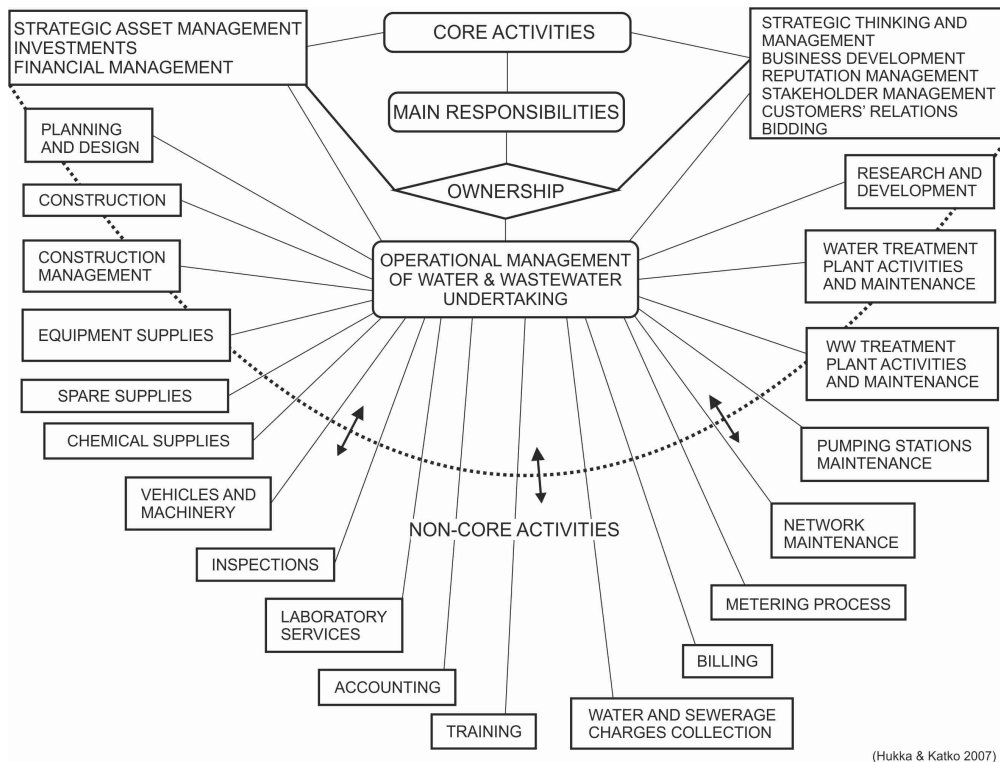


Figure 4: Suggested timeframe for water services of a quarter of a millennium: 125 years to the pasts and another 125 to the futures. The relative importance of change depends on the viewpoint and timeframe used. (Katko, forthcoming 2016)

4. Core and non-core activities of water utilities

In water services production public-private cooperation (PPC) has been practised in Finland since the early days. From strategic point of view one of the key questions is the division of core and non-core activities of utilities (Figure 5) and to what extent it is possibly feasible in various conditions to outsource the latter. Core activities may include main responsibility for required investments, strategic asset management, financial management, ownership, strategic thinking and management, bidding, business development, reputation and stakeholder management, as well as customer relations. Non-core activities, on the other hand, may include design, construction, equipment, spare and chemical supplies, vehicles and machinery, repairs, inspections, laboratory services, accounting, training, billing, meter reading, operation and maintenance, water and wastewater treatment activities, and research & development.



(Hukka & Katko 2007)

Figure 5: Core and non-core activities of water and wastewater utility (Kraemer 1998, 324; modified by Hukka and Katko 2003, modified by the authors)

Bearing in mind the difference between provision and production described earlier, the above-mentioned core and non-core activities are likely different for municipalities and, on the other hand, for water utilities. These may also be assessed through three different strategic functions: the first category being those obliged to municipalities by legislation, the second those being of major strategic importance to utilities, and the third other strategic functions.

The first mentioned core activities in Figure 5 are those closer to municipalities as utility owners. Utilities have their own strategic and operational functions. Under the latter, core activities and non-core activities can be identified. Thus, in reality the core activities and non-core activities in Figure 5 become even more complicated. In any case, it is of high importance that activities seen of strategic importance should not be outsourced.

From the point of view of education and research, it seems surprising how the current education and curriculum seem hardly to cover such strategic issues and the role of core activities. It is very obvious that these fundamental core issues cannot be left merely to continuing education and on-the-job training only. In spite of some trials on MSc Programmes or MBA programmes on Water Utilities Management, they seem not to get much ground. This is likely due to the prevailing focus on natural sciences and treatment technologies which are of course important as such. However, they are not able to give any answers to wider management, institutional, policy and governance (MIPOG) issues, such as the challenges of appropriate pricing and feasible asset management. Indeed, worldwide we have a huge challenge of proper asset

management and need for rehabilitation to rates that are likely two- or even threefold compared to the present reinvestment rates. (Hukka and Katko 2015)

5. Discussion

Instead of dramatic ad-hoc (one-time) reforms that are not uncommon in developing economies, overall evolution in Finland has mainly been based on the principle of continuous development and determined policies. This has been very evident especially in water pollution control since the 1960s. On the other hand, it may be that flexibility could have been practised more. Perhaps an example of this overall finding is the Decree on Water Pollution Control in Dispersed Rural Areas passed first in 2003. In 2011 it was revised (196/201) and in 2015 it is on the Parliament table again. Changing rules of the game for several times does not sound feasible, although there might have been some obstacles in drafting the first version.

Most likely the biggest challenge of water services in the coming 20 to 30 years in Finland and also elsewhere will be aging infrastructure, especially deteriorating networks (Heino et al. 2011; Hukka and Katko 2015). The current state of the networks in Finland is satisfactory and it will get worse unless clearly more resources are directed to rehabilitation. Compared to the experiences gained from water pollution control it seems evident that we need better “rules of the game” and institutional arrangements if we want to avoid the collapse of the current water infrastructure systems. In the case of water pollution control clear requirements and enforcement were needed. In the case of aging water infrastructure more clear requirements on long-term investments will be needed, respectively. Sector professionals and utility managers also have to take this more seriously than so far in order to convince decision-makers on the matter.

As a whole, the ways of implementing water services are in any case highly dependent on *local conditions*. Available options should be always seriously considered and accumulated knowledge be used. In water services, private, non-profit systems are justified whereas international instances on profit-maximization have produced warning examples. However, the successes of any water services can finally be assessed only from the point of view of the results: how well they have fulfilled their societal objectives.

The challenge is proper asset management and need for rehabilitation to rates that are commonly two- or even threefold compared to the present reinvestment rates. In order to improve this situation it is necessary to pay more attention to institutions, the rules of the game.

6. Conclusions

The following major conclusions can be drawn on this paper:

(i) The timeframe of viable water services development is exceptionally long, up to 125 years to the pasts and 125 years to the futures, thus a quarter of a millennium.

(ii) In education and research on water services undertakings clearly more attention should be paid to strategic functions of municipalities as owners and on the other hand those of utilities.

On the whole, it is evident that to reach more sustainable futures and water services we need to pay more attention to institutions, “rules of the game”, and even wider to management, institutional, policy and governance (MIPOG) issues including the acute challenges of appropriate pricing and feasible asset management.

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Need of Services and Understanding of Service Providers in Water and Sanitation: A Case of Ethiopia

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Abstract

Water and sanitation services are basic requirements for the development of a nation. The provision of these services should necessarily be arranged by the national government through policies, and long-term and short-term plans. Moreover, follow-up of the implementation of principle in policies and plans will determine the service level on the ground. This paper is intended to explore gaps in the policy-making and implementation in the areas of water supply in Ethiopia. Review of Ethiopian water sector policy, universal access plans, growth and transformation plans and other literature are employed to achieve the objective of this paper. Moreover, the experiences of the first author that he acquired during data collection for his doctoral study are taken into account to draw conclusions. Hence, the study shows that standards set at the federal level fail to consider the actual situation on the ground and the experts at implementation level are to interpret some aspects of the policy ambiguously. Therefore, this paper recommends the policy-makers and higher officials to consult the people in charge of putting policies in effect to have contextualized and work for uniform desired-output. Service providers need to understand the notion of the receiving community in order to provide the services that satisfy the users.

Keywords: Services, policy, service provider and service producer, water supply, sanitation

1. Introduction

Well-articulated and in-depth organized policies alone cannot guarantee the achievement of the intended goals of a country. Rather, they need to be followed by systematic regulations and directives to put them into practice (Matland, 1995). Moreover, it is not only the policy-makers who require an understanding of the real problem to be solved and the mechanisms of alleviation but also every concerned member at various levels of the government, partner organisations and the receiving communities need to know to have a successful implementation. This aspect determines the thought of policy-making if it is top-down or bottom-up as explained by Matland (1995). It should also have a favourable platform to accommodate both internal and external actors.

Platforms that are provided by national policies and strategies could guide the way of actions of governmental and non-governmental organisations, and donors in a particular country. Either from the legal or logical point of view, external imposition cannot achieve a substantiated impact in terms of contributing to the developmental strategies of countries. Support in this context means helping countries to achieve their own goals, policies and strategies (MoWR, 2001b); otherwise, the effect will be retardation.

On the other hand, the detail of a national policy on a specific agenda is very critical to accommodate both local and external partners who work in a certain sector. If it lacks clarity and depth, the implementation will still be ambiguously challenging. Moreover, in the presence of excellent policies and directives, achievements might be trivial due to the way they are understood by the members of the implementing bodies both in the governmental and non-governmental organizations. Therefore, before going into a deep analysis of the situation in the country, let us see the points boldly mentioned in the Ethiopian water sector policy.

This paper is not to make a thorough critique of the entire water policies of Ethiopia, but to make a review where improvements are suggested on how to fill the gaps observed in the area of water supply and sanitation. The main question here is how accurately the policy flows down to the community through the intermediary government levels – in other words how the policy-makers control the effectiveness of the policies? Moreover, we will try to discuss the process of policy-making based on the facts in the national programmes and make conclusions accordingly.

The rationale for selecting this subject is the remarkable national effort to the development of water supply and the visible gaps in the sector. Moreover, the merit of the expertise of the authors in the field has agitated this paper. The first author has done his research on the rural water supply of Ethiopia since 2012 and the second author was involved in a project which works for the rural water supply of Ethiopia with the collaboration of the Finnish government.

The focus of this paper is to create awareness among the Ethiopian policy-makers in the way they can think of the future and how to monitor the effective policy-making and

implementation. Moreover, the study is on Water, Sanitation and Hygiene (WASH) services in general with more focus to rural water supply.

2. Ethiopian water sector policy and development programmes

Based on the history of water resources development in Ethiopia, clear changes in the area of water supply and sanitation have been observed very recently (Behailu, et al., 2015). Moreover, the department, which was responsible for the water supply and sanitation, was not clearly placed appropriately until the active policy came into force in 2001. Earlier, the department was placed in different sectors where it had less attention, especially at the district level. During the years 2003-2004, when the administration of the country was decentralized, for the first time, a water desk under the natural resources department of the Agricultural development office was established at the district level (Calow, et al., 2012). In fact, currently, it is being transformed into an autonomous water office.

In institutionalizing the water supply and sanitation sector, the new millennium has a historical record. After the current active policy of the water sector enacted in 2001, several programmes and plans have been launched and are in operation to improve the life of citizens. These plans and programmes are water resources development strategy (MoWR, 2001b), Universal Access Plans (UAP, 2008; UAP-II, 2011 & UAP-III, 2011), WASH Implementation Framework (WIF, 2013), One WASH National Programme (OWNP, 2014) and Growth and Transformation Plans (I & II) (GTP, 2010 & 2015). These plans and frameworks have water supply and sanitation as a key component. Therefore, this paper will review them from the angle of water supply.

2.1 Ethiopian water sector policy and strategy

The Ethiopian water sector policy and strategy have comprehensively addressed irrigation, hydropower, drainage, water supply and sanitation. Water resources protection, management and optimization are well articulated in the policy, and in the case of limitation, water supply has been given priority (MoWR, 2001 a&b). The documents intensively describe the importance of clean water and sanitation as they are directly linked to the health problems of the country and base for the economic and social development (70% of the diseases in the country are waterborne (MoWR, 2001b).

As the focus of this paper is on water services, this section will review the policy and strategy from the angle of explaining water supply and sanitation. Moreover, water supply for urban and rural areas will be viewed differently since they have a different perspective in the documents. The role of administrating the urban water supply in Ethiopia is vested in the autonomous body consists of users or board. The board of the user council is responsible for rising investment capital and money for operations and, with a limited assistance from regional and federal governments, to seek loans in the case of large projects. In the case of urban water supply, the users are expected to cover the full cost – the initial cost and cost of Operation and Maintenance (O&M) (MOWR, 2001a).

In the case of rural¹ water supply, the source of initial investment is the government or external agents whereas O&M is the responsibility of the communities (Calow, et al., 2012; MOWR, 2001a&b). As a result, the policy stressed the need for user consultation to the development of such systems in order to create ownership feeling for active O&M. Thus, the success of rural water supply mainly depends on the availability of the government's capital budget and funds from donors and the O&M on the approach followed during implementations. This, in turn, significantly affects how the implementers understand the policy in the context of consultation and participation of the user community.

According to the Universal Access Plan, UAP (2008), the user community contribution should cover at least 10% of the capital cost of the projects, in order to motivate and create adequate ownership feeling. Moreover, users are deemed to cover the cost of operation and maintenance of their water system – cost recovery in the rural context is partial (MoWR, 2001a), only for operation and maintenance unlike to the urban water supply. The policy document has clearly pointed out water is not for sale since it is a public good. Therefore, service charges are to cover operations and maintenance costs, not for using the water resources. The cost recovery context here has been considered in different ways. Therefore, the tariff setting is left for the community and the rate is observed to be very small compared to the requirement for operation and maintenance (Behailu, et al., under review). According to national directives on policy and strategy, the role of tariff setting is left to the user community. Yet, the amount they agree to pay is not sufficient to cover increasing prices of spare parts.

To smooth the implementation of the policy, detail procedures and directions are provided in the water sector strategy. The strategy contains the ways the policy of water supply and sanitation from technical, financial, institutional, capacity building, social and environmental aspects. In general, it is more concerned to provide sustainable, effective, efficient, reliable and affordable services. Maybe due to the high proportion of the rural population, it recommends hand pumps as the best means to expand sustainable service. In practice, however, hand pumps are limited to the areas where there is shallow groundwater table and not universal in terms of availability. Moreover, it is susceptible to climate change as shallow groundwater is easily affected by the amount of direct recharge. Therefore, the strategy did not provide alternative solutions for the areas, which do not have plenty of surface and groundwater resources. Hand pump water systems that are installed in shallow wells will not guarantee sustainable services in communities with rapid population growth, areas that are affected by climate variability now and then, and water resources are in a declining trend.

In terms of finance, the implementation of water supply in rural areas is advised and supported by the local financial institutions like micro-financial institutions, local saving institutions and banks to access loans to implementation, operation and maintenance of water supply and sanitation systems. This is, actually, to supplement the external supports and government

¹ Rural in Ethiopia accounts for 84% of the approximately 100 million populations.

subsidies for water supply development. The strategy emphasises to maintain social equity by providing a subsidy for those who are not able to cover the cost of their services (MoWR, 2001b). However, the majority of rural communities are not able to finance water supply projects. Thus, this situation is making the work in water supply difficult to finance and address all in a short period.

Ensuring transparency, fairness, responsibility, and accountability in utilizing and managing of the WASH funds are the priorities of the strategy of the water sector. According to Calow, et al. (2012), the country has managed to maintain corruption on a low to medium level in rural water supply. However, the efficiency of systems requires improvement to operate at their full capacity.

In terms of training in the capacity building, the national water resources development strategy has attractive capacity building scheme (MoWR, 2001b), but it lacks the proper way to handle the existing trained staff not to migrate out. The shift of personnel from one organisation to the other does not matter to the overall performance of the sector, but there are areas that suffer heavily – rural areas where technical staffs do not like to work due to the lack of facilities and incentives.

2.2 Water supply in the Universal Access Plan I & II

The first Universal Access Plan (UAP) was for the period 2006-2012 and its target was to achieve the water supply coverage of 98% as a country including both urban and rural areas. The core of the first UAP was community mobilisation. Creating awareness among the community is crucial to handle the system sustainably. However, the plan was revised in 2011, to harmonize with the GTP.

In the revised version of the UAP, the rural and urban water supply were separated and designed to achieve 100% of coverage by 2015. However, the levels of services remained the same as in the previous plans such as 15 litres for rural and 20 litres for urban per capita per day in the radiuses of 1.5 km and 0.5 km, respectively.

In terms of the technical details, UAP-II has comprehensive plans that hold technical, financial, institutional and social aspects. Moreover, it has plans for operation and maintenance, rehabilitation and expansion. Otherwise, all documents of UAP have detailed the explanations of implementations of water supply systems both in rural and urban areas.

At the end of 2015, the objectives of any of the three plans have not been achieved. On top of that, the second Growth and Transformation Plan has already started with new standards, 25 litres for rural and 40 – 100 litres for urban water supplies. This implies that the new UAP will be expected very soon.

2.3 WASH Implementation Framework (WIF)

WASH Implementation Framework (WIF) is a framework formulated by four Ministries in Ethiopia, all directly involved in water supply and sanitation implementation. The goal of the framework is to bring fragmented efforts together to improve their impact. The Ministries involved in the framework are Health; Water, Irrigation and Energy; Education and Finance. In one way or the other, these Ministries have been taking part in the development of water supply and sanitation, thus, they sat down together to harmonize their efforts for greater impact.

The key elements in WIF are integration, harmonization, alignment and partnership (WIF, 2013). These elements are also the starting point in implementing One WASH National Program (OWNP, 2014). It means that WIF has paved a way for OOWNP by creating a common understanding of the four ministries, which are involved in water supply and sanitation implementation.

The point that needs to be encouraged is the action taken to harmonize the activities of WASH in the country that was fragmented. The effort of integration in the country will, at least, reduce the cost of information, and duplication efforts in the same areas. On the contrary, actors in the sector did not give attention to local situations. It seems that they are still think that one principle will work uniformly everywhere in the country. For instance, a uniform system intended for all areas will not function ideally in both agrarian and pastoralist areas. In the national policy, “water supply” includes the domestic consumption and water for cattle. Therefore, water supply services in the context of pastoralist have a wider perspective than water supply for the area where their livelihood is typically agriculture. However, the framework is sticking to 15 litres per head per day as a target to achieve.

However, the commitment of the ministries to lay the foundation of harmonization and paving the way to One WASH National Program is appreciable. This is due to the fact that the experiences of many other countries still lack the concept of resource harmonization and avoiding working independently without coordination.

2.4 One WASH National Programme

The principle of one budget, one program, and one report is the motto of One WASH National Programme (OWNP). Its objective is to harmonize actors in the sector. This actors are including donors, partner organisation (NGOs), and governmental organisation and the private sector. In the conventional way of implementation, these actors operate separately based on their preference and hence their outputs achieved can not be measured. Moreover, different actors would have worked in the same area and caused duplication of efforts. Following the WIF, the coordination of the four ministries mentioned above created a fertile ground to establish one WASH. The national government together with regional counterparts and partner organisations should lead the development direction as outlined in the OOWNP.

OWNP is launched in 2013 and is now in the implementation phase. The programme is expected to bring harmonized campaigns in the sector to address the marginalized rural, especially who are situated in the most remote areas without accessible roads.

2.5 Water in the Growth and Transformation Plan I&II

An amazing plan that has created big questions among the citizens of Ethiopians is known as Growth and Transformation Plan (GTP). It was launched in 2010 with ambitious goals that seem unachievable throughout the development sectors in the country. The plan was designed for five years and the second GTP has already started as of July 2015. Grand Renaissance Dam, Addis Ababa light train, Djibuti – Addis Ababa and Awash – Waldia – Mekkel express train projects are a few that are observed changing the image of the country. Water supply, as one of the development sectors in the country, has similar attention in the growth and transformation plan. Although the initiation of the government on the development is very appreciable, there are doubts among the citizen on the effectiveness of the plans in the short periods of the plan horizons. As indicated in Figure 1, the horizontal axis shows water supply coverage under different service levels. According to the national government, each service level has denoted by each GTP and each GTP is assumed to promote the country from one economic level to the other. In 2010, the country has designed a plan to grow from the least developed status of the lower middle income and then to the upper middle income level, before promoting to the status of the developed economy in three consecutive five-year-plans. However, it is hard to judge how many GTPs can transform a country from one economic level to the other.

Urban and rural water supply targets of the previous GTP were 20 litres per capita per day for urban and 15 litres for rural areas. Having these figures in mind the country could not achieve full coverage with this level. Nonetheless, the country again displayed a new standard of quantity supplied – 25 l/c/day for rural and 40-100 litres for urban – based on GTP 2. In fact, the service level increases through change of GTP and economic.

The point that we want to discuss at this juncture is that how the water supply systems, which were constructed for the previous standards could better fit in the new standards. Moreover, natures of the water supply schemes in the country are not in a capacity to render the GTPs proposed service level.

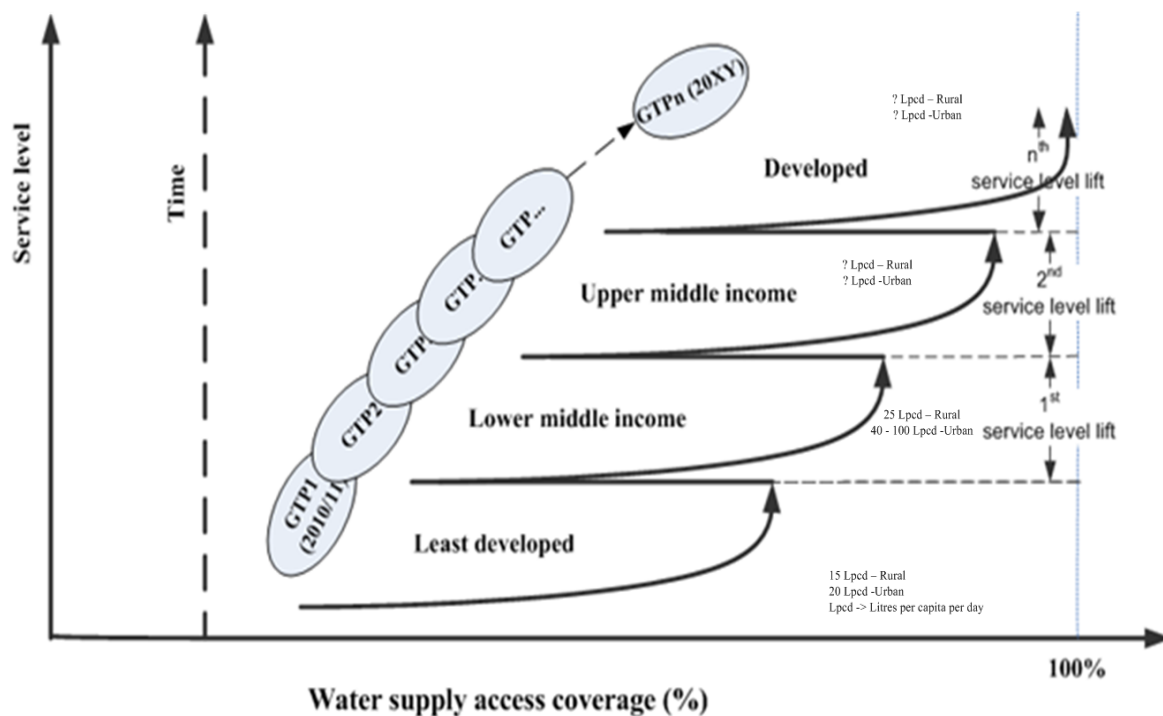


Figure 1: Tracking the Spiral Uphill Journey Path to Water Supply Universal Access to the Highest Service Level (modified from Mekonen, 2015)

3. The existing situation of services

Matland (1995) explained the top-down approach of policy-making manifested by three important drawbacks, such as lack of addressing the public objectives, excluding users and lack of a boundary between administration and policy. From these aspects, the Ethiopian water sector policy could fall under the top-down approach due to the following reasons: (1) the implementations at grassroots level are lacking pure knowledge about the policies, (2) interests of the community are not well addressed – they are driven by the consent of implementors and (3) the administration of the country is led by the political environment.

Ethiopia was celebrated for the achievement of Millennium Development Goal target 7 C in March 2015. The water supply coverage was improved by 57 % for the last couple of decades. The achievement was evaluated based on the national standard for rural and urban. The rural people are assumed to get 15 liters per capita per day and the urban 20 liters per capita per day and within the distances of 1.5 and 0.5 km, respectively (UAP, 2011). However, the study conducted in two regions of the country showed that the water supply coverage is highly subjected to insufficient service, particularly from quantity point of view. At least 40% of the populations are still without any water service. Therefore, the central point of this paper is to answer a question “How much service providers are concerned about sustainable services of the system they are in charge of?”

The served populations of the country are still uncomfortable about the service they are getting. In rural area at least 75% of the served population gets water less than 15 litres per day, which is

below the national standard. Furthermore, almost all cities in the country have frequently experienced service breakdowns and a shortage of supply. For instance, Addis Ababa (the capital city); Adama, Dire Dewa, Bahirdar, Harar, Hawassa and Mekele (Regional Capitals) and other small cities usually report for residents' complaints about water scarcity. The causes of the problems might be various, but the dominant ones are poor standards of provision and production, the instability of technical personnel, and lack of commitment to feel the pain of the end user.

Ethiopia is a country that has various climatic conditions and standards of living. Some cities have a temperature low enough to freeze water in the pipelines and some have an average temperature of over 40 degree Celsius. However, the national standards do not consider these disparities. This can be good evidence of the gaps that exist between service providers and producers. The technical personnel are more concerned in discharging their responsibility than the provision of adequate services.

According to the Ethiopian governmental structure, the district level is the most important governmental entity in facilitating services to the rural communities. However, the facilities and salaries at that level cannot attract skilled manpower. Regional, federal or non-governmental organizations attract skilled manpower. As a result, staff turnover is a common and known practice in the country. One of the threats in the growth and transformation plan (GTP) is also marked as staff turnover – 60% of skilled manpower from the total required expected to be available during the plan period. The implication of this is that the service providers are not ready to understand the rural community and not significantly concerned about the sustainable services.

4. Conclusions

The last two decades have been extraordinary for the water supply and sanitation in Ethiopia. In terms of providing policy, regulations, strategies and plans many have been done since 2001. Moreover, physical implementations of services are not insignificant, although diversified plans have been introduced to improve the coverage of the services. However, from the criteria of top-down and bottom-up approaches, the policy dominantly looks fitting the top-down approach. For example, 15 litres per capita per head is a national standard of the rural community in the country with diverse climatological regions. If the policy was bottom-up, the policy-maker would understand that this amount is not enough.

From the view of creating ownership feeling, the national government has a regulation to keep the public participation to make at least 10% contribution. The basic objective of contribution is not primarily to seek money, but to retain the involvement of the users to feel ownership and make them able to manage the systems after the implementation. However, in practice, the people at the implementation level can feel it as a burden that they must provide participation level to the government to prove the involvement of the communities. In this regard, the way of participating is not achieving its target in many cases.

Therefore, the national policy needs to be extended to every stakeholder and confirmed if policies are implemented in the sense of its original objective. Moreover, service providers or producers must shoulder the responsibility of providing intended services. To materialize these, actually, there must be a forum to create understanding among users about the future of the systems.

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Life Cycle assessment of Anti- and De-icing Operations in Norway

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Abstract

During winter maintenance in Norway 2014-2015, 225 445 tonnes of chemicals were used and 1 610 000 km driven while removing snow and ice on national and state roads. Despite this significant amount of chemicals and distance, winter maintenance is often omitted from current environmental studies of roads and transportation. Current studies focus primarily on vehicles, fuel technology and construction activities. This focus has been based on the fact that these are the largest source of emissions from road transportation. However, as vehicle and fuel technology advances and have less impact per unit, other aspects of transportation, such as maintenance and operation of infrastructure become increasingly important and should be included in LCA studies of roads in cold climates. In this study, life cycle analysis (LCA) is used to estimate the environmental impacts of the production, transport and distribution of chemicals during winter maintenance in Norway. The study is based on reported quantities for winter maintenance during an average winter between 2010-2015. The functional unit is set as anti- and de-icing operations on national and state roads per km during winter an average winter from 2010 through 2014. The results show that environmental impacts from winter maintenance are significant, and thus we argue that winter maintenance should be included in LCA of roads

in cold climates. Further investigations on current winter maintenance methods and future options are to be conducted in order to avoid solving one problem while creating another one (problem shifting) during policy development.

Keywords: Winter maintenance, highway, life cycle analysis, environmental impact, anti- and de-icing

1. Introduction

The transportation sector is estimated to be responsible for over a quarter of greenhouse gas (GHG) emissions in the world (Chapman 2007, European Commission 2015). Direct emissions from road transport are the single largest source of GHG emissions within the transportation sector, and therefore emphasis on vehicle technology and emission reduction in the use phase has been dominant (European Commission 2015). However, GHG emissions and the resulting global warming potential (GWP) is not the only impact transportation has. Other impact categories include ozone layer depletion (ODP), acid deposition and reduced air quality in urban areas, which affect human health (Colvile, Hutchinson et al. 2001).

As transport and transportation infrastructure are essential to our society, the construction of new and the handling of existing infrastructure has become a cornerstone of sustainable development (Reza, Sadiq et al. 2014, Santos, Ferreira et al. 2015). Sustainability in transport is only achieved if all aspects are optimized. Therefore, planning and designing new infrastructure as well as maintenance of existing ones are essential as roads are rarely dismantled but rather reconstructed (Stripple 2001). To be able to take into account all aspects of infrastructure life cycle analysis (LCA) is a tool often used. LCA accounts for emissions throughout the whole life cycle of a product or a service from production to the end-of-life. Additionally, LCA is useful to avoid problem shifting.

Several LCA studies have been directed at road infrastructure. These studies focus on various aspects of the transportation sector including fuel use, road construction materials, pavement options, lighting and vehicles (eg. Birgisdóttir, Pihl et al. 2006, Zhang, Keoleian et al. 2010, Huang and Parry 2014, Huang, Bohne et al. 2015). In addition, several reports have also been published especially the report by Stripple (2001) is of importance as a practical guide to LCA inventory analysis of road construction processes. Many of the processes mentioned in the report have been studied while other processes, like winter maintenance operations, have not been sufficiently explored. It is becoming increasingly important to include these operations in LCA studies on road and transport in colder climates as vehicle and fuel technology advances have led to less impact per unit.

The aim of this study is to estimate the environmental impact of anti- and de-icing operations in Norway. The results are presented in a way that allows for further use in other studies so that anti- and de-icing impact can be included in future LCA studies of roads in cold climates.

2. Winter Maintenance Operations

The general goal of maintenance operations is to ensure mobility and traffic safety, limit environmental effects, provide good service and take care of the road infrastructure capital that exists (Statens Vegvesen 2014). One of the most important method for achieving this is friction control. Friction between the tire and the pavement is essential for control of the vehicle and effects acceleration, breaking distance and directional control. Friction control is achieved by

either salting or sanding, where salting is used on roads with heavy traffic while sanding is more common on road with lower traffic (Norem 2009).

In the report *National Plan of Action for Road and Traffic Safety 2014-2017* (Statens Vegvesen 2015), where the goal of zero casualties is presented, it is shown that fatalities and severe injuries are most likely on national and state roads with total share of 37% and 45% respectively. Fatalities directly linked to weather and driving conditions were on average 16% of the total fatalities in the years 2005-2012. The category where the speed is well over the speed limits, or higher than road conditions allow for, has a share of 45% of the fatalities (Statens Vegvesen 2015). This could be directly related to road conditions. It is, however, known that drivers do not adjust their speed in proportion with reduction in road friction (Norrman, Eriksson et al. 2000). The report lists several measures to reduce incidents that include:

- Increased user awareness
- Control measures
- Motor vehicle measures
- Measures on roads.

Winter maintenance falls under the category *Measures on roads*: clearing of snow, increasing friction as well as training winter maintenance operators. Winter maintenance operations are often complicated and unpredictable and require vigilance. Of the more important tools that winter maintenance operators use are weather forecasts. However, the forecasts' quality and reliability varies, as does local situation and sudden changes in both temperature and precipitation. In a standard for operation and maintenance for roads, there are guidelines for activities that winter maintenance operators are to follow. These activities are, for example, to monitor the situation visually and through the weather forecast, use anti-icing when needed as well as de-icing and mechanical snow- and ice-removal (Statens Vegvesen 2014).

The term anti-icing is used for the action of applying chemicals to prevent wet pavements from freezing by lowering the freezing point of the water. De-icing is the act of using chemicals to remove snow and ice that have already bonded with the pavement. Additionally, chemicals are used for anti-compaction purpose where the chemicals weaken the bond between the snow crystals and prevent the snow from forming a hard crust and bonding to the pavement surface making snow removal easier (Wåhlin and Klein-Paste 2015).

In Norway, highway winter maintenance has evolved over the past decade from reactive operations towards more proactive actions. A study conducted in North America regarding operators experience shows that most winter maintenance operators felt that anti-icing and pre-wetting helped them to improve roadway safety as bare pavement was achieved more efficiently and made mechanical snow removal easier (Cui and Shi 2015). Even though salting is very helpful in winter maintenance, it is not always appropriate. In Figure 1 the temperatures and precipitation (in mm water equivalent per hour) where salting is advised, not advised or should be done with caution are presented.

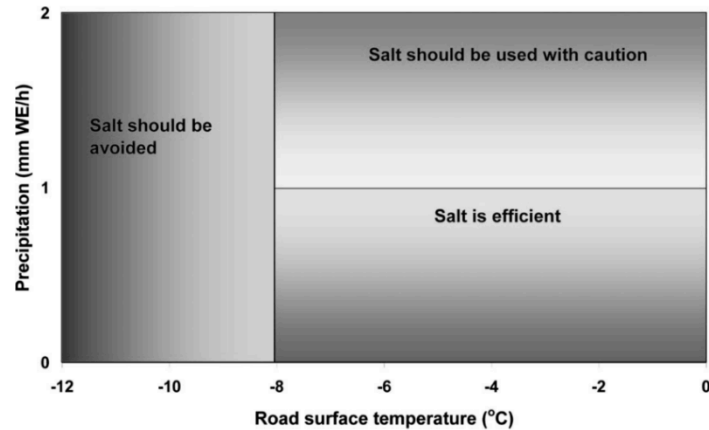


Figure 1: Weather situation and salting efficiency (Norem, 2009 p. 115)

The lower the temperature, the higher the concentration of salt must be in order to efficiently prevent ice formation and to reduce the risk of bonding between both snow crystals and snow crystals and the pavement surface. Therefore, the salt quantity is highly dependent on these weather situations shown in Figure 1 where the highest consumption is then when the weather is cold and with precipitation while salting is most efficient for temperature -8 to 0 degrees Celsius with fairly low or no precipitation (Norem 2009).

Other factors affect the amount of salt on the road are dependent on three physical processes: the initial loss, the dissolution of salt and the loss of salt (Lysbakken and Norem 2011). The initial loss of salt occurs when it is spread to the roads by wind or turbulence from the winter service vehicle (WSV) itself or because of the speed of the vehicle and spreader. The initial loss can be reduced by pre-wetting or by spreading brine. Other factors such as road surface conditions and texture as well as wind also affect the initial loss of salt. Dissolution of salt in water or brine on the road surface is mainly affected by the solubility of the chemical used and the dissolution rate. The process of salt loss includes several process where the salt leaves the road surface. These processes include salt lost by traffic as either blow-off (dry) or spray off (brine) and finally the runoff (Klein-Paste 2008). It is important that winter maintenance operators are aware of these physical processes.

3. Method

LCA is often used in assessing environmental effects from products and services in order to avoid problem shifting. LCA is therefore a very suitable tool in assessing environmental impacts of winter maintenance operations. An LCA study is conducted in four phases. First, goal and scope are defined; this includes defining the functional unit and system boundaries. Then inventory analysis is conducted where all physical products that go in and out of the system are accounted for. Environmental load of these flows are then calculated to form an impact assessment and finally the results are interpreted (International Standards Organization 2006). During each of these phases, the previous and next phase should be reconsidered in order to make any necessary changes that are revealed during the investigation. The LCA software SimaPro was used for this study, with the ecoinvent database (Weidema, Bauer et al. 2013) and calculations made with CML baseline impact assessment method.

It is very important that the inventory is carefully executed and accurately reflects use of any equipment, materials and energy. Poor inventory will only lead to high inaccuracy and maybe even wrong environmental impact results at a later stage.

3.1 Goal and Scope

The goal of this study is to map and analyse the activity of anti- and de-icing operations in Norway. The system boundaries are limited to winter maintenance operations; specifically anti-icing, de-icing and anti-compaction for increased friction and making ploughing easier. Within the system boundaries are material production and transportation as well as storage but also equipment and energy use. However, the chemicals effect on the environment after distribution is left outside the system boundaries due to lack of data.

By mapping the activities, a detailed inventory can be made to realize resource intensity. The study covers average winter maintenance operations in Norway for winters 2009/2010 through 2014/2015, from now on referred to as winter 2010 through 2015, on national and state roads. Mechanical snow removal is however outside the scope of this study.

The results are intended to be available for use by other LCA practitioners as well as winter maintenance personnel. Therefore, the results will be set up systematically, making it possible to contribute to other LCA studies that have results per kilometre to give an indication of the environmental impacts of winter maintenance.

3.2 Functional Unit

The functional unit is the very corner stone of any LCA but finding a suitable functional unit within the transportation sector can be difficult. This difficulty stems from large variations in design, location, material use, geographical profile, transportation distances and traffic load. In this study, the functional unit is the *anti- and de-icing operations on national and state roads per km during winter an average winter from 2010 through 2014*.

4. Life Cycle Inventory

The inventory for winter maintenance is quite complex and different from a more common product based inventories. It is different in the way that there is no standard recipe for achieving safe roads during the winter season. Therefore, it is necessary to base the calculation on an average. Whether it is most suitable to have an average based on the previous winter or if the last five should be used, is debatable. In this study the average of the last 5 winters was chosen as they are believed to be well documented and give good representation of an average winter in Norway. These averages will then have to be presented per kilometre for all different types of equipment, materials and transportation distances. There are few things that are constant, or could be assumed constant, between seasons. Locations of the distribution storage for example, where the ships dock and the salt is unloaded and stored, can be assumed to be fairly constant as the biggest importers have the same or similar locations (Aslaksen 2015, Heggedal 2015). In the

following section, necessary equipment and materials needed for winter maintenance are listed along with important background information.

4.1 Equipment

Equipment in winter maintenance mainly refers to the winter service vehicles (WSVs) such as trucks and their extra equipment. Extra equipment includes tanks, salt/sand spreaders and the different types of blades and ploughs. However, it also includes information about storage facilities for the salt and sand regarding type of storage, the location and possible energy use. In Norway, the most commonly used WSV is a truck or a tractor with mounted a spreader, plough, grader or loader. For highways, trucks with a mounted plough or a grader and salt spreader are the most common. These vehicles mentioned are used during and right after a weather event. Additionally, other WSV might be needed soon after a weather event to clear areas of snow for example to improve visibility or to remove compact snow and ice from the road. (Sivertsen 2015). The WSVs are owned and run by the contractors that are awarded contracts for approximately 5 years at a time. The quantity of vehicles in use during winter season is therefore difficult to determine.

Storage facilities are located at or near the shipping docks near the largest cities. These places are assumed to have storage facilities, which are warehouses with a roof and four walls. As they are assumed to have no heating and are used for a long time, they are insignificant in terms of emissions. The storage is therefore omitted from the inventory analysis.

4.2 Materials

Winter maintenance materials includes the chemicals used for anti- and de-icing. According to major importers of road salt and the largest contractors for winter maintenance operations on national and county roads, the largest share of salt is used in the south, west and mid-Norway to around the area of Trondheim. Information about the storage locations are obtained from Mesta (Heggedal 2015) and GC Rieber (Aslaksen 2015). Table 1 presents major storage facilities as well as quantity of salt in each location and percentage of the total imported salt.

Table 1: Location of salt storage facilities, quantities and share of total imported salt

<i>Location</i>	<i>Quantities</i> <i>Salt [tonnes]</i>	<i>Percentage</i>
<i>Oslo</i>	<i>65 282</i>	<i>32%</i>
<i>Arendal</i>	<i>53 408</i>	<i>26%</i>
<i>Stavanger</i>	<i>52 511</i>	<i>26%</i>
<i>Ålesund</i>	<i>11 192</i>	<i>5.5%</i>
<i>Trondheim</i>	<i>11 192</i>	<i>5.5%</i>
<i>Harstad</i>	<i>4 602</i>	<i>2.3%</i>
<i>Hammerfest</i>	<i>4 602</i>	<i>2.3%</i>

The quantities of salt that are estimated to be at these locations are based on documentation from Norwegian Public Roads Administration (NPRA) and supported by information from importers and contractors. Reported quantities of salt used in Norway seem to be stable the last years and variations can be explained by changes in weather. However, when looking farther at years prior to the years included in the study, we can see that the use of salt has increased drastically. This increase is due to salt now being used on a larger portion of the road network (Sivertsen, Lysbakken et al. 2011). As mentioned previously, anti- and de-icing operations are beneficial within a range of approximately 0 to -10 degrees Celsius. This reflects well in the information from both importers, contractors and NPRA where salt quantities are lower per kilometre in the northern and in inland regions.

Note, that the impact assessment method used does not account for the salt itself during production. Which means that the production phase accounts for materials and energy used during production as well as equipment but not any effects of salt on the local environment at the excavation site. Additionally, there are no available LCA information about the effects salt has on the environment after distribution. Therefore, effects of salt after distribution are not included in the results. However, there are few things that should be mentioned.

The focus of available environmental impact studies are on the effect of salting on the ground, surface water, soil contamination and stress on vegetation (Fitch, Smith et al. 2013). Environmental impacts of salt are localized and are dependent on various aspects such as road location and weather where precipitation, temperature and wind are of importance. The salt mainly goes directly into roadside lakes, with run-off water to nearby lakes and streams or to roadside vegetation and soil (Ramakrishna and Viraraghavan 2005). During winter, road salt is released into nature in pulses, which can lead to a rapid change of salt in the surface water. This rapid change can have deteriorating effects on the water quality. It has been shown that chloride levels in roadside stream increase dramatically and is carried downstream. With a continued build-up of chloride in lakes, it can have serious effect on the use of the water in the future. Additionally, a large proportion of the salt can leach into the groundwater where drinking water supplies can be effected by the chloride concentration. Salt contaminated run-off water may impact surface water in several ways. It can alter both physical and ecological characteristics of lakes with insufficient mixing of denser deeper layers and fresher upper layers. Seasonal mixing is essential for oxygen transfer in the lake that is necessary for continued animal and plant life in lakes. Toxic metals in sediments can also be release as a result of high salt concentration in water bodies. Release of toxic metals such as mercury can lead to lake stratification which again effects animal and plant life (Ramakrishna and Viraraghavan 2005)

The effects of salt on soil are not as serious as the effects on water. However, it has the potential to increase overland flow, surface runoff and erosion while decreasing soil permeability and aeration. The impact of salt can therefore be assumed to potentially increase emissions that contribute to categories like fresh and marine water aquatic ecotoxicity and terrestrial ecotoxicity.

4.3 Transportation

Transportation of salt is an important factor as the distance are significant. Transportation starts at salt excavation point where it is transported to the harbour. From the harbour, the salt is transported on freight ships to Norway, specifically to the locations introduced in Table 1. To estimate the freight transportation distance an online tool was used (McGraw Hill Financial 2015) and the results can be viewed in Table 2.

Table 2: Shipping distances to the different storage facilities

<i>Origin</i> <i>Destination</i>	<i>Spain</i>	<i>Tunisia</i>	<i>Germany</i>
<i>Oslo</i>	<i>4812</i>	<i>5274</i>	<i>963</i>
<i>Arendal</i>	<i>4513</i>	<i>5076</i>	<i>680</i>
<i>Stavanger</i>	<i>4410</i>	<i>5052</i>	<i>789</i>
<i>Ålesund</i>	<i>4621</i>	<i>5441</i>	<i>1248</i>
<i>Trondheim</i>	<i>5252</i>	<i>5712</i>	<i>1698</i>
<i>Harstad</i>	<i>5941</i>	<i>6276</i>	<i>2385</i>
<i>Hammerfest</i>	<i>6536</i>	<i>6628</i>	<i>2982</i>

It can be assumed that around 35% of the salt comes from Germany in the form of salt stone, while the remaining 65% come from Spain (25%) and Tunisia (40%) and are from salt lakes. To be able to calculate the environmental impact of the transport, it is important to find the average distance a kilogram of salt travels. Here the distance travelled with a freighter is 3620 km on average for each ton of salt.

The large centralized storage facilities are natural pick-up points for operators. The operators often collect salt on 30-tonne trailers (with a hanger) and either take the salt straight to distribution or drive to de-centralized storage for later use. Additionally, some of the salt is transported on smaller boats to local operators' storage facilities. The transportation distance from the central storage to a de-centralized storage is not taken into account, since commonly distributed directly.

4.4 Distribution

To be able to estimate the distribution distance, the salt quantity, which lies between 15-40 gr/m² (Statens Vegvesen 2015), was assumed 20 gr/m². The distribution distance can then be roughly calculated from the reported salt quantities used in each region. The result from these calculations are shown in Table 3. The table shows the distribution distance in kilometres for each region for year 2010-2015.

Table 3: Calculated kilometres driven during distribution of salt in each region

<i>Year</i> <i>Region</i>	2010	2011	2012	2013	2014	2015	Average
<i>East</i>	426 668	501 768	433 676	477 357	470 163	488 178	466 302
<i>South</i>	391 471	335 939	320 923	380 691	434 672	425 230	381 488
<i>Vest</i>	340 356	501 045	394 496	387 557	205 079	421 931	375 077
<i>Mid</i>	150 203	207 287	165 165	140 706	116 555	179 360	159 879
<i>North</i>	56 125	54 197	59 319	70 142	59 091	95 620	65 749
Total	1 364 823	1 600 236	1 373 578	1 456 463	1 285 560	1 610 318	1 448 495

The average distribution distance is then used to calculate the emissions per kilometre. When mechanical snow removal is conducted, which is not included in this paper, salt is most often also distributed at the same time. However, the distance calculated here is assumed to be attributed only to salting. This is done instead of reducing the distance by attributing some of it to mechanical snow removal and then adding extra distance to account for distance driven during observation.

5. Results

The results are presented for 11 impact categories. The impact categories and the origin of the emissions are shown in Table 4, where it is clear that distribution of salt in Norway is the major contributor to all impact categories, with more than 99% share of total emissions.

Table 4: Impact results per kilometre road in Norway during one average winter

<i>Life cycle stage</i> <i>Impact category</i>	<i>Production</i>	<i>Freight transport</i>	<i>Distribution</i>	<i>Total emissions</i>
<i>Abiotic depletion [kg Sb eq.]</i>	0%	0%	100%	2.42
<i>Abiotic depletion [MJ]</i>	0%	0.02%	99.98 %	1.4×10^7
<i>Global warming [kg CO2 eq.]</i>	0%	0.02%	99.98 %	8.8×10^5
<i>Ozone layer depletion (ODP) [kg CFC-11 eq.]</i>	0%	0.01%	99.99 %	0.16
<i>Human toxicity [kg 1,4-DB eq]</i>	0%	0.01%	99.99 %	4.0×10^5
<i>Fresh water aquatic ecotox. [kg 1,4-DB eq]</i>	0%	0.01%	99.99 %	1.1×10^5
<i>Marine aquatic ecotoxicity [kg 1,4-DB eq]</i>	0%	0.02%	99.98 %	2.7×10^8
<i>Terrestrial ecotoxicity [kg 1,4-DB eq]</i>	0%	0.01%	99.98 %	1.4×10^3
<i>Photochemical oxidation [kg C2H4 eq.]</i>	0%	0.07%	99.93 %	1.5×10^2
<i>Acidification [kg SO2 eq.]</i>	0%	0.11%	99.89 %	3.0×10^3
<i>Eutrophication [kg PO4--- eq.]</i>	0%	0.05%	99.95 %	7.1×10^2

The only impact category that is slightly different from the others is acidification where freight transport contributes more than to the other impact categories. However, the main source of emissions is, like in distribution, the direct emissions of burning fuel during transport.

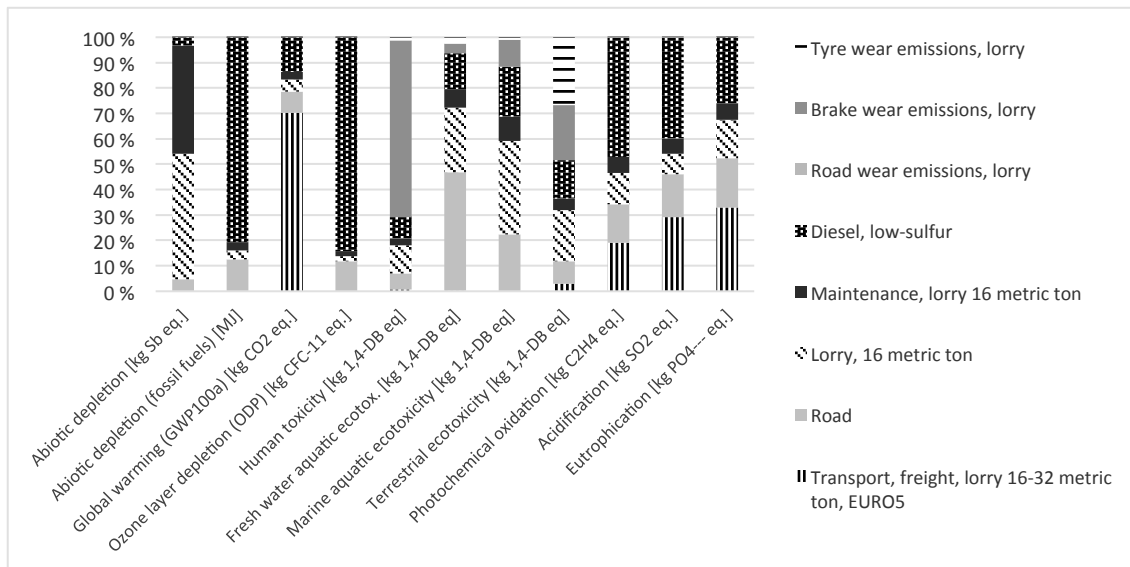


Figure 2: Emission source for the different impact categories.

Looking more closely at salt distribution shown in Figure 2, they are divided into 8 activities that contribute to the different impact categories. Towards global warming, the main contributor is the direct emission of burning fuel under transport while the production and maintenance of the truck are almost exclusively the source of abiotic depletion. The production of diesel is responsible for over 84% of the impact towards ozone layer depletion but also the largest contributor towards photochemical oxidation. Surprisingly, break wear emissions from the truck is responsible for approximately 70% of the emissions towards human toxicity.

For comparison, a Euro 5 personal vehicle would have to be driven over 2.7 million kilometres to reach the same emissions levels for global warming as is estimated emitted by salting operations in Norway.

6. Discussion

As expected, the results show that the highest impact from salting operations is from distribution in Norway. Because environmental effects of winter maintenance are highly linked to driving distances of the WSVs and material use it is important to reduce loss of salt as much as possible by optimizing speed of the vehicle and the spreader. Training and awareness of the winter maintenance staff can also contribute to less loss of salt and better winter road service. The quantities and the driving distance are however also very dependent on temperature and precipitation during the specific winter.

Furthermore, other efforts to reduce impact from winter maintenance are to focus on vehicle and fuel technology. Fuel efficiency combined with optimization of anti- and de-icing methods

could potentially reduce emissions substantially. However, it should also be kept in mind that winter maintenance operators report that especially using anti-icing is beneficial as it makes mechanical snow removal easier and results sooner in clear and safe roads. Making mechanical snow removal easier can in itself be a method of reducing emissions during winter maintenance.

7. Conclusions

Life cycle analysis (LCA) was used to estimate the environmental impacts of the chemicals used during winter maintenance and their distribution. Results on the functional unit of *anti- and de-icing operations on national and state roads per km during winter an average winter from 2010 through 2014* show that environmental impacts from winter maintenances are significant. Therefore, we argue that winter maintenance should be included in LCA of roads in colder climates. The results are presented per kilometre so it can be used in other studies to roughly include the impact of anti- and de-icing.

Further investigations should be conducted on fate of salt after salting. In addition, mechanical snow removal and future options in winter maintenance will be investigated further within the current project. By doing so, enough information should be available for decision makers to avoid problem shifting.

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Between Domestic and Public: Women's use of space in low-income urban settlements, Surabaya, Indonesia

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Abstract

Urban development has brought many changes to our built environment. Despite the changes, various values remain attached to certain places, especially in the *kampung*, an indigenous urban settlement in Indonesia. The *kampung* is a self-help settlement, where houses are built incrementally by people and the community, predominantly of low and middle income groups. It has distinct features such as heterogeneity and preservation of traditional culture. Kinship is highly valued and maintained in these settlements, which is promoted by community gatherings. The limited space in each house does not necessarily limit the interaction between residents, as they use the immediate front, side or rear part of the house as a gathering space. Women in the *kampung* play a significant role in the use of these spaces, as they connect private and public space by inhabiting these areas for their activities. This paper will elaborate on the settings and features of spaces in and around the houses that support women's relationships in the community by applying observation and interview methods. These features have proved to be successful in creating a harmonious society in the low-income urban settlement.

Keywords: domesticity, public space, women, kinship, low-income urban settlement

1. Women in Human Settlements

Women are one of the leading actors in development. Their contributions through everyday life activities are extensively recognised by scholars, principally in the context of developing countries. Moreover, the empowerment of women and their full and equal participation in political, social, ecological and economic life are essential in relation to achieving a sustainable human settlement.

1.1 Global and National Perspectives

It is now almost forty years since the initial international commitment for housing development was completed in 1976 via the UN-Habitat conference. As a commitment, it is continued to be shared in relation to different focus; one of them being the needs and contributions of women. The commitment to sustainable development as stated in Agenda 21 (1992) recognised the requirement to strengthen the role of specific groups, such as women, children and youth, so as to generate sustainable and equitable development. The beginning of the 21st century also reaffirmed the goals of gender equity and the empowerment of women through Millennium Development Goals (MDGs). From the United Nation's report (2015), the endeavour of MDG have been able to increase the number of girls enrolling in primary to tertiary education by 30%, whilst also enhancing the number of women in parliament. However, gender inequality still persists, principally in connection with access to economic assets and participation in private and public decision making. Furthermore, women remain the greatest number of urban poor compared to their male counterparts.

In the recent years, with regards to Indonesia, MDG have accomplished their particular aims in relation to the education sector. Consequently, there has been equal participation of boys and girls in primary education (BAPPENAS, 2015). The number of women members in the House of Representatives and moreover women's contribution in the non-agricultural sector are gradually increasing. However, the development is not equally distributed, especially in the eastern part of Indonesia. More importantly, there needs to be an improvement related to the quality of women's lives apart from education, labour force and political participation. Thus, to achieve sustainable and equitable developments, housing and human settlements could be part of the way forward.

1.2 Kampung in Surabaya

It is worthwhile indicating that a kampung is not a slum (Funo, 2002), nor a marginal settlement (Silas, 1989). To a certain extent it is an urban village developed incrementally by the inhabitants and which has certain characteristics. These features are defined by Funo (2002) as variety, heterogeneity and autonomy, consisting of a highly serviced society, preservation of traditional culture and complexity of ownership relations and mutual aid system. By variety, it means that there are various characteristics of a kampung related to its establishment, such as the migratory background of the inhabitants, economic activities, spatial layout, and so on. For

example, based on the geographical situation (distance from the city centre) a kampung can be divided into three types: urban, fringe and rural kampung.

Kampung have been an important part of the development of Indonesian cities, especially in Surabaya, the capital of East Java province and second largest city of Indonesia. Approximately 70% of the settlements in Surabaya are self-built by the community. There is a practice called ‘*gotong royong*’ (working together), which is deeply ingrained in the lives of the kampung’s inhabitants. This might be one of the reasons that community based programmes, such as the Kampung Improvement Programme (KIP) undertaken from the 1970s to the 1990s were well received and organized by themselves.

1.3 The Research

This study is part of a PhD research about women and housing in a low-income urban settlement. It was conducted in two kampung communities in Surabaya; Jambangan and Rungkut Lor. With regards to the geographical situation, Jambangan is a fringe kampung, while Rungkut Lor represents an urban kampung. The different location (urban or fringe) means that there are differences (to a certain extent) in terms of density and infrastructure. Based on economic activities, most of the inhabitants in Jambangan are traders and public or private employees, whereas in Rungkut Lor, residents are mostly industrial workers from Surabaya’s neighbouring city. The different conditions of these two kampung might provide different backgrounds for women in using space especially at the neighbourhood and urban level.

This paper examines how women use the space in and around the house to perform their activities which relates to social relationships through gender perspectives. Observations and interviews are applied in conjunction with photographs and drawings. In dealing with the private and personal data, it is compulsory to obtain consent prior to the interview, so that every participant gave their permissions to publish the data. This includes using their real name in the document. The participant list in Table 1 describes only the women that are part of the discussions in this paper, but not all of the participants in the study. It is worth noting that there are two main activities which connect these women together as participants; environmental activity (recycling) in Jambangan and economic activity (making snacks) in Rungkut Lor.

Table 1. List of Participants

No.	Name	Age	Kampung	Notes
1.	Bu Mustaqim	44	Jambangan	a mother of two, sister of bu Bayu, active in recycling centre
2.	Bu Bayu	49	Jambangan	a mother of two, sister of bu Mustaqim, sells traditional drinks for additional income
3.	Bu Nur	47	Jambangan	a mother of two, neighbour of mbak Fitri, active in recycling centre
4.	Mbak Fitri	39	Jambangan	a mother of three, neighbour of mbak Fitri and cousin (by marriage) to bu Riana, active in recycling centre
5.	Bu Riana	49	Jambangan	a mother of three, cousin (by marriage) to mbak Fitri, runs a juice stall in the food court nearby
6.	Bu Pri	50	Rungkut Lor	a mother of three, a grandmother, neighbour of bu Latifah

7.	Bu Latifah	43	Rungkut Lor	a mother of two, neighbour of bu Pri, earning income from sewing clothes
8.	Mbak Titin	30	Rungkut Lor	a mother of one, selling traditional snacks.

2. Space and Social Relationships

We use space in many ways, as it serves many purposes. Lawson (2001) suggests that through space we can express individuality or support solidarity, gather people together or set them apart, while also conveying sets of rules within society. One of the many relationships that space can accommodate is the kinship network; while at the same time the kinship relation may shape how space is used. Space as it was traditionally defined by architecture is the space determined by architect or designers, whilst in gendered discourse, space is rather as it is found, used, occupied and transformed through everyday activities (Rendell et al., 1999:101). Public and private realms, kinship networks and social relations of exchange have been particularly important in examining the differing spaces men and women are allocated culturally, and the particular role space has in symbolising, maintaining and reinforcing gender relations (Ardener in Rendell, 2002:9).

2.1 Domesticity: Public and Private Realms

...women's experience in the city is not one of creating boundaries, drawing limits, or establishing categories; it is one movement in the margins, between and through categories, connecting rather than distinguishing and relishing contradictions rather than rejecting them (Andrew, 2000:158).

Public and private are only one of the dichotomies related to the use of space, among others such as outside/inside, economy/family, work/home, duty/love (Jarvis et al., 2009:10). These separate spheres are usually associated with male and female respectively. However, as Andrew (2000) mentioned above, the use of space by women is not neatly patterned; instead it is more likely intersections between multiple identities. Women have different roles as wives, mothers, sisters, neighbours, and income earners. These roles are juxtaposed in the efforts of creating home comfort. Therefore, the role of women in defining home comfort is predominant. Rybczynsky (1987) suggests that privacy is one of the principal attributes in relation to home comfort in 17th century Europe. In this context, the idea of privacy is closely related to domesticity, as they both deal with the intimate part of a house. Subsequently, the notion of comfort then developed historically, and now has multiple layers of meaning, which include leisure, pleasure, efficiency and convenience. Modern discussions on domestic architecture are more broadly related to house and dwelling, the architecture of the everyday, as it challenges the notion of domesticity, which refers to the idea of the division between work and home, between male and female spheres, public and private space, regarding the difference between genders (Heynen and Baydar, 2005).

As domesticity changes meaning through time, it also varies culturally. In the case of traditional Madurese settlements in East Java, Indonesia, domestic activities such as cooking and bathing may take place outside the house, in a compound setting (Faqih, 2005). Although more often

than not in modern settlements the kitchen and bathroom are located inside the house, the traditional custom of cooking outside the house is still conducted in the urban settlement, especially in the kampung, where women use the alley or front terrace to cook. In this sense, domesticity is not connected to privacy, but more in relation to the role of gender, where domestic spaces relate to women's use of space.

Bu Nur's house is one example of this. When the family renovated the property in 2010, she decided to have the kitchen at the front instead of at the back. Consequently, it occupies the space of front yard of the old house. The kitchen is connected to the front terrace by a stable door (Figure 1), which makes it practical when she bakes biscuits every year during the Islamic festive months, assisted by her neighbour. The large oven for the biscuits will be placed on the front terrace and any activity requiring kitchen utensils can be easily accessed straight from the front terrace. More than a practical reason, this example also gives an idea of how domesticity is played out in the house. The activity of cooking as one of the 'private' activities of the household has shifted into a more public domain, driven by economic motives.

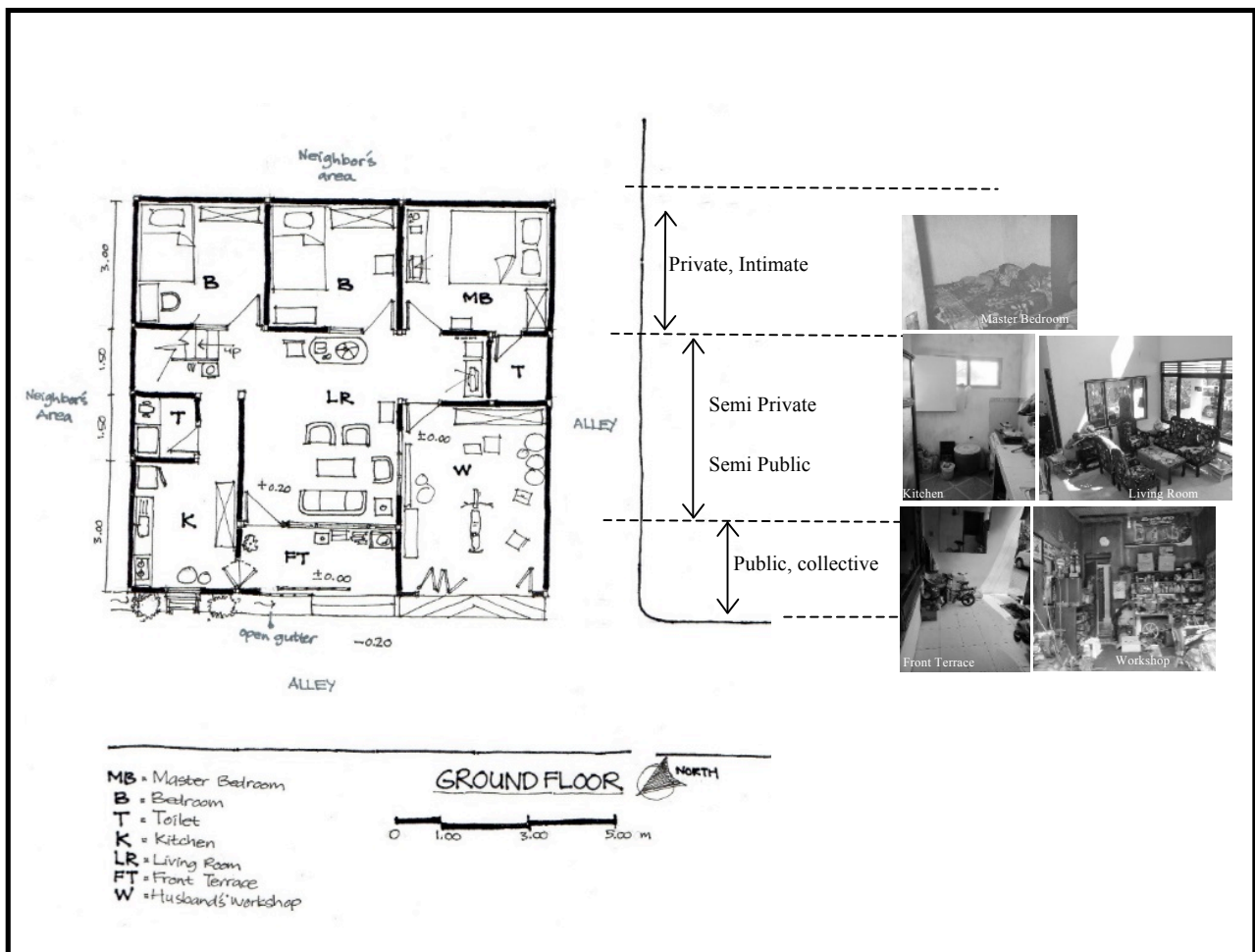


Figure 1. Bu Nur's house plan, the kitchen and terrace are connected by a stable door

2.2 Kinship: Biology and Culture

Discourse on kinship, principally from the anthropological point of view has tended to rest on the distinction between the biological and the social, the natural and the cultural (Carsten, 2004). Kinship as proposed by Sahlins (2013) is the **mutuality of being**, in which people are intrinsic to one another's existence. It is socially constructed, aside from consanguinity or affinity relationship. This is evident in many cultures, especially in Southeast Asia via a study by Rosaldo in 1980, where the Ilongot society in the Philippines share 'blood' through a history of migration and through research conducted by Carsten in Malaysia in 2004, which observed the sharing of food and co-residence in forming kinship (Sahlins, 2013: p.8).

In Javanese social structure, the nuclear family is the most important part of a kinship unit (Geertz, 1989:4). Therefore, we can observe the relationship between people through how they identify each other. Moreover, Geertz also suggests that social security within the family is significant for the functioning of Javanese society as a whole. By social security it means that in case something happens within the nuclear family (for example, parents become ill) a support system is provided by the surrounding community. This condition is still relevant today as almost all of the participants have family or relatives within the area.

A participant in Rungkut Lor, Mbak¹ Titin, lives in rented rooms near her parents, who also rent a house in the neighbourhood. She first moved to Rungkut Lor in 2005 due to the work she had at a factory in Rungkut Industrial park. Later on, her parents moved into the area to live closer to their children (their other daughter lives in Tenggilis, a neighbouring settlement located about two kilometres from Rungkut Lor). By having parents who live nearby, it is easy for Mbak Titin to go to training and other activities conducted away from home, since she can leave her 2 year old daughter under her parents' care. Bu² Pri, another participant in Rungkut Lor also has a son who is married and rents a room nearby. She will then gladly look after her granddaughter during the day while her son and daughter in-law are working.

The research participants in Jambangan share different forms of kinship, from biological to cultural. For example, Bu Mustaqim and Bu Bayu are siblings. They live nearby on the same plot of land, although in different houses. Bu Riana and Mbak Fitri are related by marriage, as their husbands are cousins. In addition, more than being just a biological relationship, kinship is culture. Bu Nur and mbak Fitri's relationship evidently demonstrates the notion of kinship that is shaped by human engagement, rather than naturally given.

The different forms of social relatedness in some ways affect the way women use space (between participants). For example, in the first case, during one interview with bu Mustaqim, she told her first son to park the motorcycle in bu Bayu's place because the usual parking space

¹ mbak is used as a form of politeness when calling an older – although there is not a huge age gap – woman, and literary means sister.

² 'bu' is the abbreviation of 'ibu', and literary means mother. It is often used before the forename in Indonesia to show respect to an older lady and is similar to the use of Mrs.

was being used for the interview. On another occasion, Bu Mustaqim kept some stuffs for bu Bayu in her house. Thus, this reveals that both of them use their separate house space in various ways as one unit, where they can interchangeably use each other's space without having to first ask for permission. This practice of shared space is not evident in the second case of bu Riana and mbak Fitri. The practice of sharing spaces is also evident in the third case of mbak Fitri and bu Nur, where they do not share a biological relationship, but share activities and experiences. The difference with the first case is that this shared space operates on a mutual basis, rather than equality, as can be noted in the first case. These three examples of relationships demonstrate the different practices incorporated in shared space, used by women.

Bu Nur and mbak Fitri have both lived in Jambangan since they married. As women who married a local man, they both have to live with the in-laws during the first years of their marriage³. This experience forms the basis of their relationship. Afterwards, both of them became involved in the same activities, such as the recycling centre, *posyandu* (children's healthcare) *arisan* (community gathering) and community savings. Simple everyday life activities, for instance baking biscuits and grocery shopping enabled their relationship to grow stronger and thus, they are like sisters. Furthermore, Mbak Fitri's son and daughter call bu Nur and pak⁴ Slamet, *Budhe* and *Pakdhe*. This is how nieces and nephews call aunts and uncles in Javanese. Their close relationship can be perceived, as they mention it in the interview:

"...when we renovated the house, we did not move, we only used the existing two rooms, and when the new rooms were done, we used them while the builder worked on the other rooms. It lasted for two months, so we used the bathroom of bu Slamet (bu Nur) during that time. We still have some stuff there (in bu Nur's house) because now our space is so limited. Bu Slamet is always suggesting that my son should use their upstairs bedroom later when they finish renovating the house. But I still feel reluctant..."

[Fitri, 39 years old, 10 June 2015]

In the interview with me, mbak Fitri referred to bu Nur as bu Slamet (her husband's name) to show her courtesy and respect; while in daily interactions, she will call her 'mbak' Nur. It shows her close relationship with bu Nur, while at the same time maintaining the highest respect for her in front of me, the researcher. This courteous manner is also shown in her reluctance to let her son sleep in bu Nur's house. This reluctance however is not evident as she allows her first daughter to live with her brother-in-law's family in another city. In fact, this confirms evidence of how in Javanese culture, the concept of family is still closely related to blood relations.

As for bu Nur, mbak Fitri is a source of support in many ways. She assists her not only in community activities such as the recycling centre and children's healthcare, but also in her

³ It is common practice in the Javanese patriarchal system that the oldest or only son of the family will stay in the parents' house after marriage to look after them.

⁴ Pak is the abbreviation of 'bapak' and literary means father. It is often used prior to the forename in Indonesia to show respect to an older man and is similar to the use of Mr.

economic activity (baking biscuits to sell), in particular when she became more dependent on her after the motorcycle accident that affected her ability to travel as easily as before:

“...the accident was about two years ago, and happened right in front of the house. I wanted to go to buy porridge for my husband’s sister, as she was sick, when all of a sudden I fell and could not get up. I then realised I couldn’t see my knee, and I screamed. The neighbours started coming, and among the first to come is Mbak Fitri’s husband [...] since the accident, I go with mbak Fitri to the market...”

[Nur Isaroh, 47 years old, 10 June 2015]

Bu Nur lives in a two-storey house with 4 bedrooms (the second floor was under construction, one room is used to store mbak Fitri’s belonging), while mbak Fitri occupied one room in the family-owned rented rooms (Figure 2). In addition, their houses are only about 20m apart. Mbak Fitri’s son is voluntarily helping pak Slamet (bu Nur’s husband) in the construction of the house, helping to carry the bricks, cement, and other materials. In this case, the use of space in another person’s house is exchanged with other forms of activity, when house space is limited or not available to other party.



Figure 2. Bu Nur's house (left) and Mbak Fitri's house (right)

2.3 Settings and Features of Kampung that Supports Kinship Values

In general, two types of space are occupied by women in the *kampung* which supports their social relationship. First is the space that was built or occupied on purpose, whereas the second is the immediate space in or around the house. The first space is primarily used by the women at certain times and for specific activity, while the second differs through time and activities.

2.3.1 Time and Activity-based Settings

The first type of space is promoted by the same primary activity, such as recycling in Jambangan and making snacks in Rungkut Lor. To accommodate this activity, each woman’s group makes the effort, in order to have a specific place. Beyond the main activity, the relationships between these women also involve the social, cultural and economic aspects of

their everyday life. For example, while doing the recycling and making snacks, they share information on raising children, community savings, undertaking the daily shopping with the cart seller that passes by or just by sharing stories. In another way, this relationship develops kinship as they have become mutually related. Thus, kinship configures how the space is used.

In Jambangan, this type of spatial configuration was evident in the recycling centre. This particular activity was first initiated in 2012, when the kampung participated in an environmental programme; 'Green and Clean' initiated by the city council. It started as a simple greening activity, and then developed into a recycling centre. With the recycling activity, more space was needed to store the recycled objects before they were collected by partner recycling agents. This facility was established as the woman's group asked the district office to provide them with more space for their activity and is constructed from very simple materials. On one occasion during the election campaign, the woman's group secured a donation to upgrade the building, as is shown in Figure 3. In Rungkut Lor, this type of space was a rented room, paid for by the cooperation of women who conduct the business. Here in the rental space, they receive purchase orders, receives guests and buyers, bake some of the biscuits, and also hold meetings. Both the spaces are relatively small, approximately 30 m²; nevertheless they are adequate enough to accommodate the women's activities.



Figure 3. The recycling centre in Jambangan (left) and Kampung Kue Secretariat in Rungkut Lor (right)

2.3.2 Immediate Space around the House (Time-based)

The second type of space appropriation is the immediate space in or around the house. It is the space that is available in the first place, although it can be used in different ways, based on certain times and activities. For example, the terrace of a public reading room in Rungkut Lor was utilised at dawn to sell snacks and cakes not only for the neighbourhood buyers but also by other traders within the surrounding traditional market, as revealed in Figure 4. Aside with public facility, a number of people used the immediate space adjacent to or in front of their own houses (Figure 5).



Figure 4. The use of public reading room in the kampung at dawn (left) and noon (right)



Figure 5. The use of immediate space in front of the house for economic activity at dawn (left)

Another feature in the kampung that also has a significant role in creating and maintaining the social relationship between women in this setting are the benches (Figure 6). These come in different shapes and materials - from simple wood planks to more permanent concrete blocks and are usually located in front of the house. In general, they tend to be used from the afternoon until dusk (between 4 to 6 pm). This is the time where most of the women in the kampung have spare time (they watch children play, water the plants, exchange tips on cooking or tell each other interesting stories). It is also the most convenient time in relation to tropical weather to be outdoors.

Bu Latifah who spends most of the time inside the house because she sews clothes to make ends meet, recalls the ritual afternoon meeting on the benches as one way for her to strengthen her relationship with her neighbour during the first months of her stay in 2010. Nowadays, it is also a way for her to release stress after spending hours inside the house.



Figure 6. Different types of bench in Jambangan and Rungkut Lor

2.3.3 Immediate Space of the House (Activity-based)

The most common space in the house used by women to perform community activities is the front terrace. The activities comprise: *arisan* (monthly gathering), *pengajian* (weekly Qur'an recital) and *posyandu* (fortnightly children's healthcare). These spaces were used by prior arrangement, depending on the activities schedule. One example is the children's healthcare activity (Figure 7). In Jambangan, it was organised on every first and third Wednesday of the month. At the time the activity took place, children aged less than 5 years old were weighed, their height measured and on occasions they were given vaccines by a health practitioner.



Figure 7. Children's healthcare activity occupying the front terrace of the house

3. Moving Beyond Binaries

The examples above reaffirmed that women's use of space, principally in kampung, is not that of using separate spheres, but instead moves beyond the binaries of public/private, work/home, outside/inside, and even duty/love. We can see from the aforementioned examples that domestic space in this context is gender related and is less associated with the private sphere; thus it can occupy a public sphere. This might inform a different notion of domesticity as in most European and North American literatures which mostly relate with home and privacy (Rybczynski, 1987; Kent, 1990; Lane, 2007).

A further interesting finding is how a certain space is used primarily by women, despite its location in public areas. It appears to indicate the strong agency of women in claiming their own space. Women use space not only dependant on activities, but also on social relationships. Therefore, kinship relations play an essential role in how these spaces are used, while at the same time these spaces with their different activities can nourish and strengthen the social relationships between women. In the context of low-income urban household, where the limited space of the house may encourage more shared use of public space, this interrelationship is therefore determinants in creating a harmonious urban settlements.

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INTERNATIONAL COMPARISONS OF CONSTRUCTION LABOUR PRODUCTIVITY

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Abstract

Comparing productivity of industry between countries is a crucial information base for research in comparative analysis and policy making. This comparison enables identification of shortcomings in one place and then look for ways to deal with them. The construction industry is characterised by heterogeneity and uniqueness of its product, complexity of its delivery process and industry structure and the country specificity of construction products. Aggregate quantity measures of construction are normally done with monetary value of construction output. The monetary value of construction output are normally converted with the market exchange rates into the same currency for comparisons of construction production across countries. The comparison is always distorted by the volatility of market exchange rate. An alternative is using Purchasing Power Parity (PPP). PPP is a neutral way of stating the ability of one nation's currency to purchase goods in different nation costs recorded in various national currencies in a single currency. Newly published Purchasing Power Parity data from the World Bank's International Comparison Program 2011 and employment statistics maintained by the International Labour Organization (ILO) are used to generate comparable data of the construction labour productivity (CLP) of 93 economies and the Construction Labour Productivity Indexes (CLPIs). The CLPI is the standardised index of the construction labour productivity of an economy relative to the world average. CLP tends to be higher in the high economies than the low income economies. CLP measures of the two methods are tending towards convergence as the economies grow from developing to developed status. CLP shows a relatively stronger correlation with nation's economic growth based on exchange rates. Construction industry is changing from being a long-established non-international traded industry to a more complex international traded industry.

Keywords: Productivity, Construction industry, International comparisons, Purchasing power parity

1. Introduction

GDP per capita, a common measure to provide an assessment of the performance of the market economy and to monitor cyclical fluctuations, is simply labour productivity multiplied by the proportion of the population that works. In the absence or difficulty to construct a perfect alternative metric, GDP is still being commonly used to understand what makes countries rich and the underlying causes of productivity change. A country's productivity is the average of its industries productivity weighted by its size. Therefore to understand what makes countries rich is best achieved by evaluating the performance of individual industries. Such a micro approach reveals the importance of industrial productivity (Lewis, 2006).

Construction is an important industry because its output is large and it represents a significant part of the economy. It produces investment goods which are vital for the wellbeing of any economy. In most countries, construction provides about half their gross domestic fixed capital formation (Hillebrandt, 2000). The world construction industry stands at 5.5% of world Gross Domestic Product (GDP) in 2013 (United Nation Statistics Division, 2014).

On the other hand, low productivity in the construction industry has been a constant concern. To raise economic performance, it needs to focus on the causes of productivity differences among companies, industries, sectors, and countries. The international comparisons form a crucial information base for research in comparative analysis and policy making. It is difficult to compare construction products between economies because the construction industry of each economy is basically unique. The complexity and the country specificity of its products results with no two economies build exactly the same kind of house or power station (The World Bank, 2015). The most commonly used method for such international comparisons is to express the GDP of the countries concerned in the same currency unit so that the differences in the economies are readily identifiable. There are long recognized shortcomings in GDP as a measure of economic performance such as home production, technological obsolescence and environmental degradation or depletion of natural resources are excluded in the measurement of GDP (Stiglitz, et.al. 2009). This comparison is exaggerated when the economy's foreign-exchange rates is used to convert its national currency. An alternative approach to overcome volatility of market exchange rate in the comparison is to replace exchange rate with purchasing power parity (PPP) as conversion factor (Todaro & Smith, 2015). PPP is the ability of one nation's currency to purchase goods in a different nation. It compares how different currencies function in the same country, rather than trying to compare different currencies in different countries (Taillard, 2013).

The following section highlights in more detail the problems of making international comparisons, introducing the concept of PPP and International Comparison Programs by the World Bank and summarising the PPP approach to construction expenditure by the World Bank's International Program. It explains the different productivity measures and justifies the single factor gross output measure used. The next section provides details of the sources of data for the construction expenditure and construction employment statistics of the different economies. Section 4 compares the results the construction labour productivity and

Construction Labour Productivity Indexes (CLPIs) of 93 economies computed in this study. Section 5 discusses the productivity differences between the economies based on PPPs and exchange rates. Section 6 concludes the findings of the study.

2. International Comparisons

International comparisons of levels and more importantly of rates of growth play a very important role in the policy design. It enables structural reforms to import the “best practice” of the country performing the best in terms of productivity, if the productivity of the two countries are computed in the similar way. Reported National Accounts are good sources of data to be drawn for international comparisons. Comparisons are indeed possible if the procedures and definitions used to compute the accounts are comparable, but there are still large differences in the ways National Accounts calculations are carried out (Stiglitz, et.al. 2009).

The main issue in the international comparison is the inconsistency of definitions used in national measures of construction activity. In addition, the output of construction is so heterogeneous, aggregate quantity measures of construction is not feasible, and using monetary values is the only option (Meikle & Gruneberg, 2015). Often costs are converted to USD (or any other currency) in order to compare costs between countries. The supply and demand for currencies are influenced primarily by factors such as currency speculation, interest rates, government intervention, and capital flows between economies. A high exchange rate will make local costs look high against the comparison country. A low exchange rate will do the opposite (Turner and Townsend, 2015). Comparing national economies via measures such as gross domestic product (GDP) using exchange rates can be very much distorted by price-level differences between countries (Best & Meikle, 2015). The differences between the levels of GDP in two or more economies reflect both differences in the volumes of goods and services produced by the economies and differences in the price levels of the economies. They do not reflect the relative purchasing power of currencies in their national markets (The World Bank, 2015).

Many goods and services such as buildings, government services, and most household market services are not traded internationally (The World Bank, 2015). The volatility of exchange rates can distort a country’s construction costs compare with others in international comparisons of construction activity (Meikle & Gruneberg, 2015).

2.1 Purchasing Power Parity

PPP removes the impact of volatility of exchange rates (Turner and Townsend, 2015). The International Comparison Program (ICP) conducted under the charter of the United Nations Statistical Commission (UNSC) provides globally comparable economic aggregates in national accounts (The World Bank, 2015). It is the principal source of data on the PPPs of currencies, real domestic product and real per capita income. The latest round of the ICP 2011 participated by 199 economies provides the full set of results for 177 economies, accounts for about 97 percent of the world’s population and 99 percent of the world nominal GDP (The World Bank,

2015). The participating economies report their expenditures that are valued at national price levels in national currencies i.e. nominal expenditures. These nominal expenditures are converted to real expenditures (i.e. expenditures that are valued at a common price level) by PPPs (The World Bank, 2015). Real expenditures reflect real or actual differences in the volumes purchased in economies and provide the measures required for international volume comparisons (The World Bank, 2015).

ICP comparisons are designed to compare the volumes of goods and services that enter GDP at specific points in time. They are not designed to measure the relative rates of growth in GDP between these points. Each ICP comparison produces indexes of real GDP that show the relative volume levels of GDP among participating economies for the reference year. When the indexes for consecutive reference years are placed side by side, they appear to provide points in a time series of relative GDP volume levels over the intervening years (The World Bank, 2015).

PPPs are calculated in stages: first for individual goods and services, then for groups of products, and finally for each of the various levels of aggregation up to GDP (The World Bank, 2015).

2.2 Purchasing Power Parity of Construction Expenditure

Construction expenditure is one of the 25 sub aggregates expenditure reported in ICP 2011. It includes capital expenditure on the construction of new structures and renovation of existing structures. Gross fixed capital formation in construction is broken down into three basic headings: residential buildings, non-residential buildings, and civil engineering works (The World Bank, 2015).

The economies of Eurostat-OECD used the bill of quantities approach in comparison. All the economies are required to price the Bill of Quantities of a common set of standard fictitious buildings and civil engineering projects on the basis of the actual structures and materials and methods commonly used in their construction. Each economy was expected to price 7 out of 11 standard construction projects specified using prices of successful tenders submitted during the reference year. The price includes the contractor's mark-ups for general site costs, head office overheads, profit and cost of employing professional architects and engineers. The PPPs for construction are calculated using the overall prices of the projects (The World Bank, 2015).

The Commonwealth of Independent States (CIS) economies used a modified version of the bill of quantities. These economies were required to provide unit prices for 66 inputs covering materials and labour for the regional coordinating agency in order to price simpler and less complete bills of quantities of an extensive range of model structures. The PPPs for construction were calculated using the overall prices for the model structures (The World Bank, 2015).

Other participating economies were required to collect unit prices for 38 kinds of basic building materials, the hourly cost of hiring five types of building equipment with and without an operator. The economies were also asked to include the hourly rate at which compensation was

paid to construction workers across 7 occupations and for a common set of 55 inputs. They had to indicate the types of structures for which each of the inputs was commonly used and the average resource mix for each of the three basic heading. PPPs for the basic heading were obtained by aggregating the PPPs of its subheadings with subheading expenditure weights (The World Bank, 2015).

2.3 Labour Productivity

The productivity measures can be classified as single factor productivity or multifactor productivity. The single factor productivity relates a measure of output to a single measure of input, whereas the multifactor productivity relates a measure of output to a bundle of inputs (Organisation for Economic Co-operation and Development, 2001).

These measures capture the movements of output with gross output or value-added. When measured as gross output per unit of labour input, labour productivity rises as a consequence of outsourcing and falls when in-house production replaces purchases of intermediate inputs. This does not reflect a change in the individual characteristics of the workforce and a shift in technology or efficiency. The efficiency gain as a consequence of input substitution will not be captured (Organisation for Economic Co-operation and Development, 2001).

Value-added based labour productivity measures tend to be less sensitive to processes of substitution between materials plus services and labour than gross-output based measures. When outsourcing takes place, labour is replaced by intermediate inputs. This will reduce value added and hence lead to a fall in the labour productivity. At the same time, outsourcing means less labour input needed, this will lead to a rise in the labour productivity. Because labour productivity measures reflect the combined effects of changes in capital inputs, intermediate inputs and overall productivity, they do not leave out any direct effects of embodied or disembodied technical change. The embodied technical change enhances production possibilities for a given set of inputs, while the disembodied technical change operates via capital goods and intermediate inputs (Organisation for Economic Co-operation and Development, 2001).

The choice of productivity measures depends on the purpose of productivity measurement and the availability of data. Labour productivity relates to the single most important factor of production, is intuitively appealing and relatively easy to measure. It partially reflects the productivity of labour in terms of the personal capacities of workers or the intensity of their efforts and how efficiently labour is combined with other factors of production. It also reflects how many of these other inputs are available per worker and how rapidly embodied and disembodied technical change proceed (Organisation for Economic Co-operation and Development, 2001).

3. Research Methods

This paper used single factor productivity measure, based on gross output. It is simply the ratio of the quantity of gross construction output to quantity of labour input. The construction expenditure found in the ICP 2011 is used as the proxy for gross construction output. The expenditure includes capital expenditure on the construction of new and renovation of existing residential buildings, non-residential buildings, and civil engineering works. The quantities of labour input is obtained from the International Labour Organisation's central statistics database (ILOSTAT). ILOSTAT provides recent labour data for over 100 indicators and 165 economies. Employment by construction that are used as proxies of quantity of labour input are extracted from the section of *Employment by Economic Activity and Occupation* of the databases (International Labour Organization, 2015).

There are 93 matching pairs of economies found in the employment statistics of ILOSTAT and construction expenditure in ICP 2011. They account to 82.5% of real construction expenditure and 89.9% of nominal construction expenditure. The computed construction labour productivities and Construction Labour Productivity Indexes (CLPIs) based on PPPs and exchange rates of these 93 economies are available in Appendix I. The construction labour productivity of different economies needs to be expressed in the same currency unit so that the differences in productive levels of different economies are readily identifiable.

The CLPIs are standardised indices expressed by the construction labour productivity of an economy relative to the world average productivity level, which is set at 100. Economies with CLPIs greater than 100 shows their construction labour productivity levels are higher than that of the world average. Economies with CLPIs less than 100 indicates their construction labour productivity levels are lower than that of the world average.

For analytical purposes the World Bank classification of economies is used in the discussion. The World Bank classifies economies as low income, middle income, or high income. As of 1 July 2011, low-income economies are those that had average 2010 incomes of not more than \$1005; lower-middle-income economies had average incomes of \$1006 to \$3975; upper-middle-income economies had average incomes of \$3976 to \$12 275; and high-income had average incomes of \$12 276 or more. Low- and middle-income economies are commonly referred to as developing economies (World Bank, 2011). There are 49 high economies, 26 upper middle income economies, 16 lower income economies and two low income economies.

4. Results

It is apparent from Table 1 that CLPs of 80 economies are higher based on PPPs measurement method, leaving CLPs of 13 economies are higher when based on exchange rates. The former are low, lower middle, upper middle and partially high income economies and the latter are all high income economies. It suggests that developing economies tend to understate the construction labour productivity if based on the exchange rates measurement.

Table 2 shows the top 10 construction productivity and CLPIs of high income economies. CLPs of all the selected economies are higher based on PPPs with exceptions to Finland, France and Sweden. CLPI of Belgium is slightly below world average based on exchange rates, but appears as two times of world average when measured by PPP.

Table 1: Comparison of number of economies with higher CLP based on different measurement methods

<i>World Bank classification</i>	<i>Number of economies</i>	<i>Number of economies with higher CLP based on PPPs</i>	<i>Number of economies with higher CLP based on exchange rates</i>
<i>High income</i>	49	36	13
<i>Upper middle income</i>	26	26	0
<i>Lower middle income</i>	16	12	0
<i>Low income</i>	2	2	0
<i>Total</i>	93	80	13

Table 2: Top 10 CLPIs of high income economies

<i>Economies</i>	<i>Nominal consumption (based on exchange rates)</i>		<i>Real consumption (based on PPPs)</i>	
	<i>Construction expenditure/ construction employment</i>	<i>CLPI (world = 100)</i>	<i>Construction expenditure/ construction employment</i>	<i>CLPI (world = 100)</i>
<i>Norway</i>	164 883	140.20	239 836	335.36
<i>Australia</i>	127 261	108.21	227 640	318.30
<i>Switzerland</i>	152 675	129.82	224 479	313.88
<i>Canada</i>	192 678	163.83	213 732	298.86
<i>Finland</i>	199 997	170.05	194 469	271.92
<i>Netherlands</i>	169 527	144.15	191 795	268.18
<i>Denmark</i>	179 506	152.63	184 002	257.29
<i>France</i>	206 154	175.29	183 479	256.56
<i>Belgium</i>	110 622	94.06	168 909	236.18
<i>Sweden</i>	183 807	156.29	157 615	220.39

Table 3 shows the top 10 construction productivity and CLPIs of upper middle income economies. CLPs all the selected economies are higher based on PPPs. CLPIs of Romania and Albania achieved approximately two-third of world average when measured by exchange rates. But they performed marginal higher than world average when based on PPPs. Kazakhstan's CLPI is lower when based on PPP.

Table 4 shows the top 10 construction productivity and CLPIs of lower middle income economies. CLPs all the selected economies are higher based on PPPs. CLPIs of Indonesia is about half of world average when measured by exchange rates, it appears 35% higher than world average if it is based on PPPs. The CLPIs of Armenia, Georgia, Moldova and Ukraine are lower when based on PPP. Bhutan's CLP appears to be the highest among the 93 economies but it has a relatively smaller size of construction industry. Its construction expenditure in 2011 was USD 720 million and employed 4500 construction workers.

Table 3: Top 10 CLPIs of upper middle income economies

<i>Economies</i>	<i>Nominal consumption (based on exchange rates)</i>		<i>Real consumption (based on PPPs)</i>	
	<i>Construction expenditure/ construction employment</i>	<i>CLPI (world = 100)</i>	<i>Construction expenditure/ Construction employment</i>	<i>CLPI (world = 100)</i>
<i>China</i>	122 119	170.76	361 219	307.14
<i>Seychelles</i>	93 528	130.78	213 840	181.83
<i>Romania</i>	47 420	66.31	134 817	114.63
<i>Montenegro</i>	47 336	66.19	103 673	88.15
<i>Mexico</i>	46 035	64.37	88 701	75.42
<i>Albania</i>	44 298	61.94	128 236	109.04
<i>Colombia</i>	42 678	59.68	89 253	75.89
<i>Turkey</i>	41 891	58.58	102 283	86.97
<i>Kazakhstan</i>	41 736	58.36	56 466	48.01
<i>Costa Rica</i>	35 380	49.47	76 702	65.22

Table 4: Top 10 CLPIs of lower middle income economies

<i>Economies</i>	<i>Nominal consumption (based on exchange rates)</i>		<i>Real consumption (based on PPPs)</i>	
	<i>Construction expenditure/ construction employment</i>	<i>CLPI (world = 100)</i>	<i>Construction expenditure/ Construction employment</i>	<i>CLPI (world = 100)</i>
<i>Bhutan</i>	159 595	223.16	680 664	578.77
<i>Indonesia</i>	34 681	48.49	158 391	134.68
<i>Mongolia</i>	33 156	46.36	112 181	95.39
<i>Armenia</i>	31 598	44.18	37 377	31.78
<i>Georgia</i>	24 015	33.58	29 674	25.23
<i>Sri Lanka</i>	19 897	27.82	83 397	70.91
<i>Senegal</i>	15 806	22.10	45 437	38.64

Morocco	14 853	20.77	75 983	64.61
Moldova	14 770	20.65	18 098	15.39
Ukraine	13 742	19.21	20 002	17.01

Table 5 shows the construction productivity and CLPIs of the two low income economies, Ethiopia and Zimbabwe. Both CLP and CLPI of the two economies are higher when based on PPPs.

Table 5: CLPIs of low income economies

Economies	Nominal consumption (based on exchange rates)		Real consumption (based on PPPs)	
	Construction expenditure/ construction employment	CLPI (world = 100)	Construction expenditure/ Construction employment	CLPI (world = 100)
Ethiopia	9,225	12.90	55 759	47.41
Zimbabwe	6,398	8.95	17 111	14.55

Table 6 shows in low income economies, CLP is 4.7 times of exchange rate when based on PPP. Ratios of CLP based on PPPs to CLP based on exchange rates are gradually narrowed to 3.5, 2.6 and 1.3 times in lower middle income, upper middle income and high income economies respectively.

Table 6: Average expenditure per capita and construction labour productivity based on PPP and exchange rates group according to economic development status

World Bank classification	Average expenditure per capita based on			Construction labour productivity based on		
	PPPs	Exchange rates	PPPs/ exchange rates	PPPs	Exchange rates	PPPs/ exchange rates
High income economies	39 692	38 750	1.02	140 865	107 176	1.31
Upper middle income	14 367	7 497	1.92	97 196	37 471	2.59
Lower middle income	6 727	2 809	2.39	89 689	25 597	3.50
Low income	1 296	524	2.47	36 435	7 811	4.66

It is apparent from Figures 1 and 2 that, there is a strong correlation between construction labour productivity and expenditure per capita when they are based on exchange rates. Figure 1 shows that the coefficient of determination (R^2) of construction labour productivity and the expenditure per capita is 0.10 when they are based on PPP. However, the coefficient of determination (R^2) increased to 0.60 when based on exchange rate (Figure 2). This is equivalent to correlation coefficient (R) of 0.77.

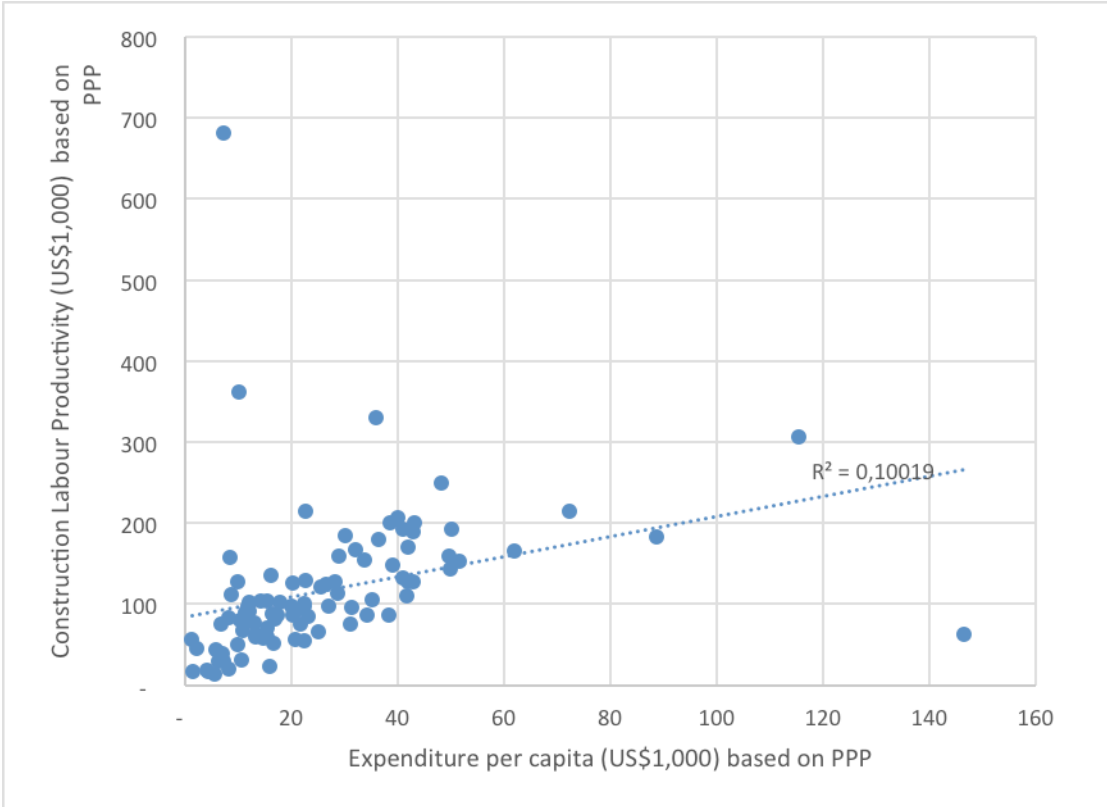


Figure 1: Construction labour productivity and expenditure per capita based on PPP

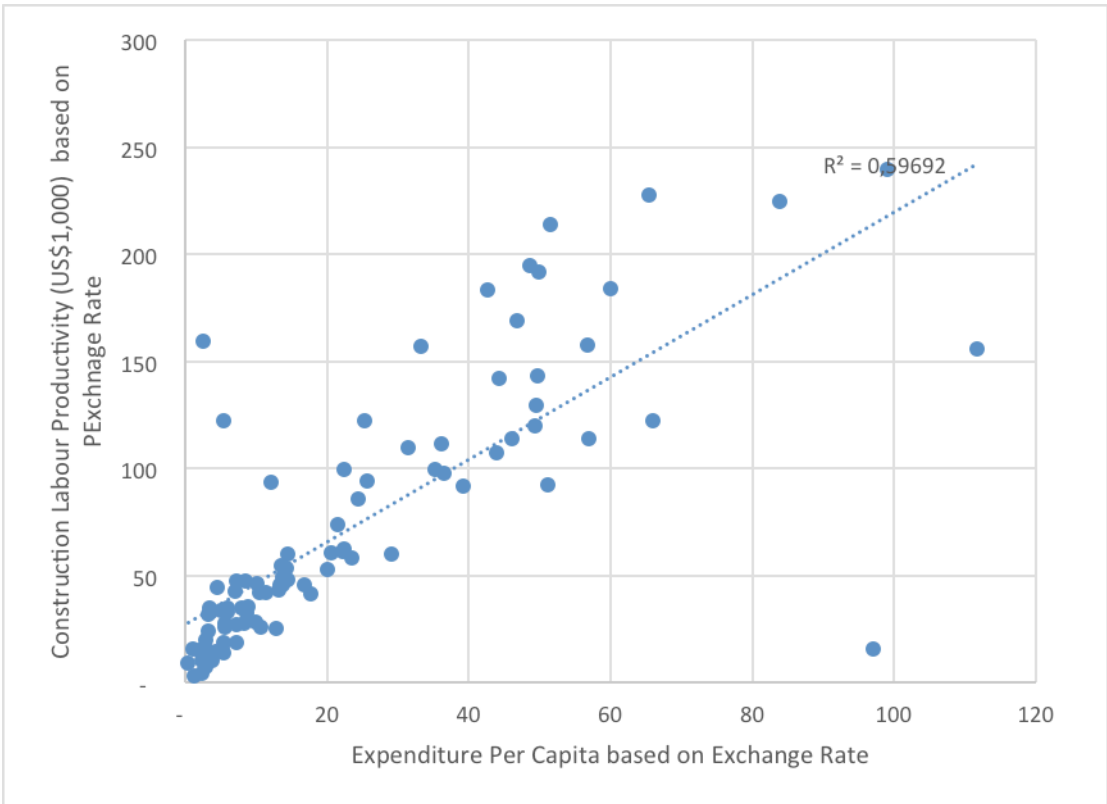


Figure 2: Construction labour productivity and expenditure per capita based on exchange rate

5. Discussion

The above analysis shows exchange rates measurement of construction productivity tends to understate the CLPs. It is mainly because construction is an industry relying mostly on the local supplying of resources, such as materials and labour and it also depends on local demand for its output.

CLP tends to be higher in the high income economies than the low income economies. One possible reason for this is that construction industry in the higher income economies have a better opportunities for capital investment and replacing on-site manual works with mechanisation and off-site production.

In higher-income economies, the differences between CLP measures in PPPs and exchange rates are less compared to the low-income economies. The two methods of measurement are tending towards convergence as the economies grows from developing to developed status (Table 6). CLPs and economic development shows stronger correlation when based on exchange rates (Figure 2). This suggests that CLP will eventually be strongly influenced by the exchange rates. Construction industry is changing from being a long-established non-international traded industry to a more complex international traded industry. With the globalization of the world economy, today's construction business is fast becoming an internationally interdependent marketplace. According to the ENR (2014), the Top 250 International Contractors had USD 543.97 billion in contracting revenue in 2013 from projects outside their home countries, up 6.4% from USD 511.05 billion in 2012. Data published by ENR shows that ENR's top 225 international contractors in 2011 earned USD 453 billion in revenue from construction projects outside their home countries, which represents more than a two-fold increase over the USD 189.4 billion recorded in the last ICP 2005. In addition, with the rise of modern industrialized countries, increasingly complex civil engineering projects are being procured, and the increased scale of these projects has provided a launching pad for international construction. Advanced technology, fast transportation, convenient communications, effective knowledge transfer, integrated markets and trade liberalization have all helped to lower traditional barriers and transform construction into a fiercely competitive international marketplace where construction companies ebb and flow (Lu, et al., 2015).

6. Conclusions

Statistical analysis is subjected to alternative interpretations because they serve a multiplicity objectives. Policies and best practices may be drawn from inferences of statistical analysis. This paper attempt to compare the productivity of the construction industries of different economies in order to identify the high and low performance economies to uncover their underlying determinants of productivity performance in the further studies. Further researches need to be aimed at taking stock of what already been done, and assessing the strengths and weaknesses of these practices in order to shape the industry's future policy.

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Appendix 1 – Construction labour productivity on PPP and exchange rates in 2011

	World bank classification	Expenditure in construction		Construction employment (Thousands person)	Construction productivity			
		PPP (U.S. dollars, billions)	Exchange rates (U.S. dollars, billions)		USD / (PPP) employment	Index (world = 100)	USD / (Exchange rate) employment	Index (world = 100)
Norway	H	61,879	99,035	189.9	164,883	140.20	239,836	335.36
Australia	H	42,000	65,464	1013.9	127,261	108.21	227,640	318.30
Switzerland	H	51,582	83,854	274.0	152,675	129.82	224,479	313.88
Canada	H	41,069	51,572	1294.6	192,678	163.83	213,732	298.86
Finland	H	38,611	48,686	176.2	199,983	170.05	194,469	271.92
Netherlands	H	43,150	49,888	438.1	199,997	170.06	191,795	268.18
Denmark	H	41,843	60,030	159.5	169,527	144.15	184,002	257.29
France	H	36,391	42,728	1885.4	179,506	152.63	183,479	256.56
Belgium	H	40,093	46,759	337.5	206,154	175.29	168,909	236.18
Bhutan	LM	7,199	2,600	4.5	680,664	578.77	159,595	223.16
Sweden	H	41,761	56,704	309.5	110,622	94.06	157,615	220.39
Israel	H	30,168	33,259	162.5	183,807	156.29	157,050	219.60
Luxembourg	H	88,670	111,689	39.2	182,156	154.89	155,719	217.74
United States	H	49,782	49,782	9039.0	143,268	121.82	143,268	200.33
Germany	H	40,990	44,365	2576.8	132,940	113.04	142,067	198.65
Austria	H	42,978	49,590	354.2	127,117	108.09	129,373	180.90
Macao SAR	H	115,441	66,063	28.3	305,957	260.15	122,469	171.25
Aruba	H	36,017	25,355	4.2	329,689	280.33	122,314	171.03
China	UM	10,057	5,456	17248.0	361,219	307.14	122,119	170.76
Ireland	H	42,942	49,383	107.8	189,143	160.83	119,622	167.26
Japan	H	34,262	46,131	5020.0	86,161	73.26	113,936	159.31
Cayman Islands	H	49,686	56,883	3.2	159,829	135.90	113,749	159.05
Italy	H	33,870	36,180	1791.2	154,327	131.22	111,454	155.84
Spain	H	32,156	31,534	1403.9	167,482	142.41	109,929	153.71
Iceland	H	38,226	43,969	10.0	86,830	73.83	107,394	150.17
Korea, Rep.	H	29,035	22,388	1750.7	158,699	134.94	99,343	138.91
Hong Kong SAR	H	50,129	35,173	277.0	192,501	163.68	99,243	138.77
New Zealand	H	31,172	36,591	172.0	74,616	63.45	97,956	136.97
Greece	H	26,622	25,654	245.8	123,895	105.35	94,053	131.51

Appendix 1 – Construction labour productivity on PPP and exchange rates in 2011

	World bank classification	Expenditure in construction		Construction employment (thousands person)	Construction productivity (PPP)		Construction productivity (Exchange rate)	
		PPP (U.S. dollars, billions)	Exchange rates (U.S. dollars, billions)		USD / employment	Index (world = 100)	USD / employment	Index (world = 100)
Seychelles	UM	22,569	12,196	2.1	213,840	181.83	93,528	130.78
Singapore	H	72,296	51,242	402.7	214,864	182.70	92,255	129.00
United Kingdom	H	35,091	39,241	2202.1	105,104	89.37	91,871	128.46
Slovenia	H	28,156	24,480	54.2	127,832	108.69	85,667	119.79
Bahamas	H	22,639	21,490	14.3	129,530	110.14	73,778	103.16
Portugal	H	25,672	22,396	423.1	121,938	103.68	62,106	86.84
Malta	H	28,608	22,201	11.6	113,118	96.18	60,882	85.13
Czech Republic	H	27,045	20,592	431.0	96,723	82.24	60,597	84.73
Croatia	H	20,308	14,429	117.9	126,460	107.53	60,071	84.00
Cyprus	H	31,229	29,208	45.9	95,358	81.08	59,846	83.68
Saudi Arabia	H	48,163	23,594	1293.7	248,933	211.67	58,159	81.32
Latvia	H	19,994	13,658	60.9	97,609	83.00	54,657	76.43
Lithuania	H	22,521	14,212	85.1	100,747	85.67	53,577	74.92
Taiwan	H	39,059	20,030	830.6	147,983	125.83	53,002	74.11
Hungary	H	22,413	13,790	260.1	96,892	82.39	49,355	69.01
Chile	H	20,216	14,546	620.3	87,150	74.10	48,239	67.45
Romania	UM	16,146	8,549	631.3	134,817	114.63	47,420	66.31
Montenegro	UM	14,128	7,244	11.7	103,673	88.15	47,336	66.19
Mexico	UM	16,377	10,115	3716.8	88,701	75.42	46,035	64.37
Poland	H	21,753	13,382	1278.9	75,223	63.96	45,771	64.00
Estonia	H	23,088	16,821	58.9	85,278	72.51	45,591	63.75
Uruguay	H	17,343	13,722	120.3	87,055	74.02	45,405	63.49
Albania	UM	9,963	4,467	72.4	128,236	109.04	44,298	61.94
Russian Federation	H	22,502	13,298	5106.4	55,387	47.10	43,294	60.54
Colombia	UM	11,360	7,142	1144.7	89,253	75.89	42,678	59.68
Turkey	UM	17,781	10,435	1674.5	102,283	86.97	41,891	58.58
Kazakhstan	UM	20,772	11,358	614.0	56,466	48.01	41,736	58.36
Slovakia	H	25,130	17,762	241.0	66,477	56.53	41,546	58.09

Appendix 1 – Construction labour productivity on PPP and exchange rates in 2011

	World bank classification	Expenditure in construction		Construction employment (thousands person)	Construction productivity (PPP)		Construction productivity (Exchange rate)	
		PPP (U.S. dollars, billions)	Exchange rates (U.S. dollars, billions)		USD / employment	Index (world = 100)	USD / employment	Index (world = 100)
Costa Rica	UM	13,030	8,935	123.8	76,702	65.22	35,380	49.47
Serbia	UM	11,854	6,027	118.7	97,928	83.27	34,941	48.86
Indonesia	LM	8,539	3,511	6324.5	158,391	134.68	34,681	48.49
South Africa	UM	12,111	7,963	1054.5	90,342	76.82	34,611	48.40
Macedonia, FYR	UM	11,957	5,050	40.0	101,554	86.35	33,361	46.65
Mongolia	LM	8,719	3,701	52.0	112,181	95.39	33,156	46.36
Peru	UM	10,981	6,066	866.2	80,006	68.03	32,980	46.12
Mauritius	UM	15,506	8,611	54.1	103,792	88.25	32,666	45.68
Armenia	LM	6,696	3,363	67.4	37,377	31.78	31,598	44.18
Malaysia	UM	20,926	9,979	1133.6	93,417	79.43	28,351	39.64
Belarus	UM	16,603	5,596	400.8	51,831	44.07	27,774	38.84
Panama	UM	15,369	8,411	162.0	60,070	51.08	27,578	38.56
Bulgaria	UM	15,522	7,284	228.7	70,051	59.56	26,798	37.47
Dominican Republic	UM	10,858	5,541	244.2	66,760	56.77	25,997	36.35
Venezuela, RB	UM	16,965	10,731	1117.7	81,385	69.20	25,636	35.85
Brazil	H	14,639	12,874	7814.4	58,637	49.86	25,305	35.38
Georgia	LM	6,343	3,231	65.2	29,674	25.23	24,015	33.58
Sri Lanka	LM	8,111	2,836	508.5	83,397	70.91	19,897	27.82
Azerbaijan	UM	15,963	7,285	308.9	23,059	19.61	18,869	26.38
Algeria	UM	13,195	5,518	1791.0	58,700	49.91	18,399	25.73
Senegal	LM	2,243	1,123	131.6	45,437	38.64	15,806	22.10
Qatar	H	146,521	97,091	497.5	62,358	53.02	15,754	22.03
Ecuador	UM	9,932	5,226	382.4	49,904	42.43	15,420	21.56
Morocco	LM	6,764	3,074	1059.0	75,983	64.61	14,853	20.77
Moldova	LM	4,179	1,971	66.8	18,098	15.39	14,770	20.65
Tunisia	UM	10,319	4,340	441.7	79,765	67.82	14,320	20.02
Thailand	UM	13,299	5,395	2173.4	63,334	53.85	14,110	19.73
Ukraine	LM	8,295	3,575	1311.9	20,002	17.01	13,742	19.21

Appendix 1 – Construction labour productivity on PPP and exchange rates in 2011

	World bank classification	Expenditure in construction		Construction employment (Thousands person)	Construction productivity (PPP)		Construction productivity (Exchange rate)	
		PPP (U.S. dollars, billions)	Exchange rates (U.S. dollars, billions)		USD / employment	Index (world = 100)	USD / employment	Index (world = 100)
Guatemala	LM	6,971	3,247	265.4	39,195	33.33	12,554	17.55
Paraguay	LM	7,193	3,836	199.0	30,065	25.56	10,264	14.35
Philippines	LM	5,772	2,379	2091.0	43,435	36.93	9,987	13.96
Ethiopia	L	1,214	353	380.6	55,759	47.41	9,225	12.90
Egypt, Arab Rep.	LM	10,599	2,888	2716.0	30,802	26.19	7,186	10.05
Zimbabwe	L	1,378	695	101.8	17,111	14.55	6,398	8.95
Bolivia	LM	5,557	2,360	393.5	13,667	11.62	4,340	6.07
Pakistan	LM	4,450	1,255	4414.5	16,650	14.16	3,113	4.35

H = High income, UM = Upper middle income, LM = Lower middle income, L = Low income

Source: Computed from ICP 2011 and employment database maintained by ILOSTAT

Influence of construction time on the productivity of construction works

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Abstract

Construction time has a major influence on the economically viable execution of construction works. Any short (or very short) construction period will severely affect the effective utilisation of production factors, which influences not only elementary (labour, materials, equipment and machinery) but also discretionary (project managers, site managers, technicians etc.) production factors. Clients often do not recognise this effect, or even deny it. Productivity is adversely affected not only by too short but also by exceedingly long construction times.

This paper demonstrates the basic correlation between construction time and productivity. Own approaches and methods known from pertinent literature are presented and critically reviewed to be able to quantitatively assess losses of productivity. This paper illustrates the influence of construction time on costing and, consequently, the actual construction process. Construction managers will be made aware of the necessity to closely monitor those construction-related factors that have an influence on construction time.

Another factor that deserves increasing attention is the gradual (“notional”) shortening of construction time. Very often, more work needs to be performed than originally agreed upon whereas the construction period remains the same, and the contractor has to cope with a deterioration of the conditions under which work is to be executed. In most of these cases, contractors are forced to accelerate processes “incrementally” to adhere to the agreed-upon construction period, which partly incurs significant additional costs to be covered by the contractor if the client is not notified of the related disruptions based on the merit of the individual case.

Overall, this paper should create a better understanding of factors that promote or inhibit productivity whilst raising awareness of disruptions to the construction process, with the aim to further improve the effective utilisation of production factors but also to identify, and subsequently evaluate, thresholds of productivity losses more easily.

Construction time influences both the quality of individual processes and work steps and the overall quality of the project, as well as the number of construction process disruptions and thus the amount of additional costs claimed.

Keywords: construction time, productivity, production factors, costs, construction process disruptions

1. Introduction

Construction management is characterised by a combination of production factors. Pricing is essentially determined by defining which production factors to combine in which way and at what points in time. As part of the zero-base costing exercise (i.e. calculating cost-covering prices of construction works to be performed at a later point in time, excluding speculative elements), the expected costs of construction works must be determined. The costing exercise uses various construction work scenarios that are “played back” as a mental “construction film”. The type and combination of production factors required for the construction work scenario that is considered most likely at the time of bid costing are applied.

Costs result from the consumption of production factors that is measured in monetary amounts. The intensity of this consumption is essentially driven by the time available for construction. The final bid pricing should always be determined on the basis of a zero-base costing exercise. At the very least, this approach makes bidders aware of the risk/opportunity range in which their quoted final prices lie. If the client specifies a construction period that is shorter than normal, and if the bidder then decides to quote a price that is, say, 20% lower than the zero-base level, the bidder should at least be fully aware of the fact that it runs a very high project risk. In such a case, it is often no longer possible, even if production factors are combined in an optimal fashion, to make up for this deficit that exists already at the beginning of the construction phase.

2. Production system

In construction management, production factors include elementary (labour, equipment and machinery, materials) and discretionary factors (project managers, site managers, technicians etc.). Production factors are particularly influenced by environmental and ambient conditions. Any effective or efficient construction process is characterised by combining these production factors in an optimal fashion. This optimal combination is reached if and when production factors can be employed at a “normal productivity” level (cf. Hofstadler (2014); Produktivität im Baubetrieb; pp. 13).

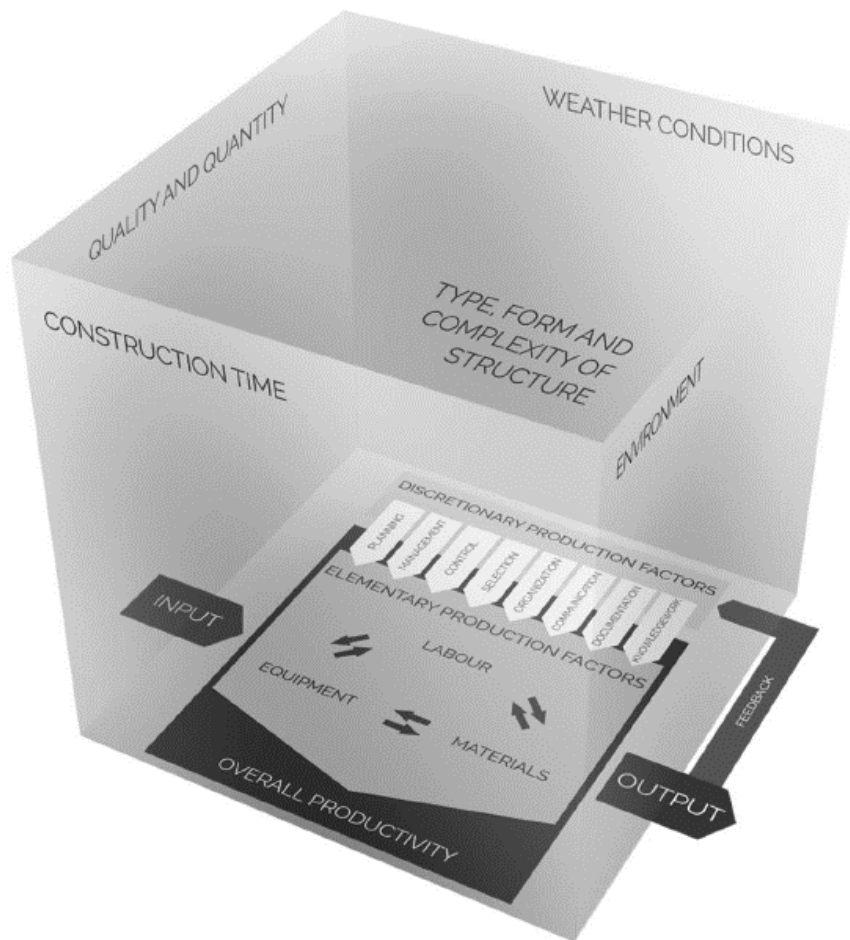


Figure 1: Influence on total productivity

The way in which production factors can be combined in a cost-effective fashion essentially depends on the type, shape and complexity of the structure as well as on the conditions governing work performance (see Fig. 1). Furthermore, achievable total productivity is determined by the required quality features and quantities, construction time, the site environment, and – last but not least – by prevailing weather conditions.

Any new construction project will always be subject to different boundary conditions; production factors must be adjusted to the specific circumstances of the project.

3. Importance of construction time

Construction time influences the project in many different ways. This parameter is relevant not only in terms of construction management and economics but also from a legal point of view. Construction time influences individual quality features as well as total quality and the number of disruptions to the construction process, and thus additional cost claims.

Generally speaking, sufficiently long periods must be scheduled for preparing quotations and construction activities and for actual work performance on the job site. Additional factors to be considered when determining normal construction time include seasonal effects and specific site conditions as well as other influential factors and difficulties.

Whenever short construction times coincide with a specified high quality standard of the building or structure and adverse weather conditions, this setting leads to a particularly unfavourable situation.

4. Specification of construction time

Construction time is usually specified by the client or principal. Contractors use this information to derive the utilisation of production factors required to fulfil their contractual duties. Labour consumption rates serve as a baseline indicator for all labour-intensive activities; labour consumption rates are subsequently used as key input variables to calculate output values. Bidders use labour consumption rates as an important basis for their costing and final pricing exercise.

How do production factors and productivity develop over the period of construction? This question is crucial for both preparatory project measures to be implemented by the client and for the costing exercise carried out by bidders and contractors as well as for work execution and the billing of construction works. Clients are well-advised to thoroughly deal with the question of which intensity of production factor utilisation is most appropriate and useful to prevent any risk to achieving their project targets (quality, completion date, costs etc.). As a matter of course, clients are free to neglect this issue and to rely on a comprehensively worded construction contract. However, this approach might be associated with major disadvantages in terms of the project outcome (including cost overruns, quality issues and construction delays) because, obviously, any building or structure will always be constructed not by virtue of a mere contract but by an appropriate combination of production factors. It is the purpose of the construction contract to provide a proper framework for performing and billing construction work as well as rules for conflict resolution. It would thus also be advisable for the client to deal with the change in productivity and production factors over time. Bidders and contractors are bound to do this anyway because they would otherwise not be in a position to prepare a source-based costing exercise and to write the “optimal screenplay” for executing construction works (including spatial, temporal and intensity-related progress of work steps). In this context, the following question needs to be answered: Which trend should be assumed with regard to productivity and production factors during the construction period?

There will always be fluctuations in productivity because it will not remain constant over the entire period to project completion. When evaluating productivity, the individual project phases must be considered in relation to work performance (see Fig. 2). The following basic distinction can be made:

- Productivity during the ramp-up phase (D_{RU} = duration of ramp-up phase)

- Productivity during the main construction phase (D_{MC} = duration of main construction phase)
- Productivity during the final phase (D_{FP} = duration of final phase)

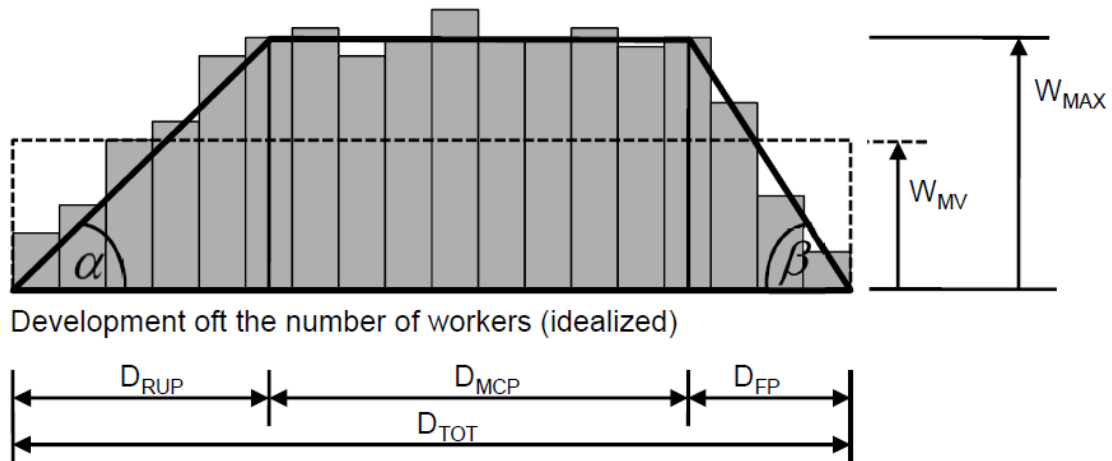


Figure 2: Number of workers on the construction site; see Hofstadler (2014), p. 14

Disruptions to the construction process are particularly disadvantageous in the ramp-up and final phases because optimally adjusted resources are not yet or no longer allocated to site operations.

4.1 Significance of construction time for the construction contract

By specifying construction time, the client exerts a direct influence on costs, and thus on construction prices. Construction times that are too short lead to losses of productivity and to higher costs. In the short term, higher costs are incurred, for instance, if the planning-ahead process does not work as intended or if other circumstances related to work performance (within the scope of the client) have changed. At a later stage, this situation will lead to issues caused by poorer structural quality as well as medium to long-term obstructions of use due to changed maintenance and repair scenarios. Limits for losses of productivity are still partially unknown or open to dispute.

Provided the client specifies normal construction times, contractors are in a position to optimally combine their production factors so as to perform their work owed under the contract at the lowest possible construction cost whilst adhering to the allocated budget (see Fig. 3). Thus, there is a lower risk of non-compliance with the specified construction time and cost as well as the agreed-upon quality standard.

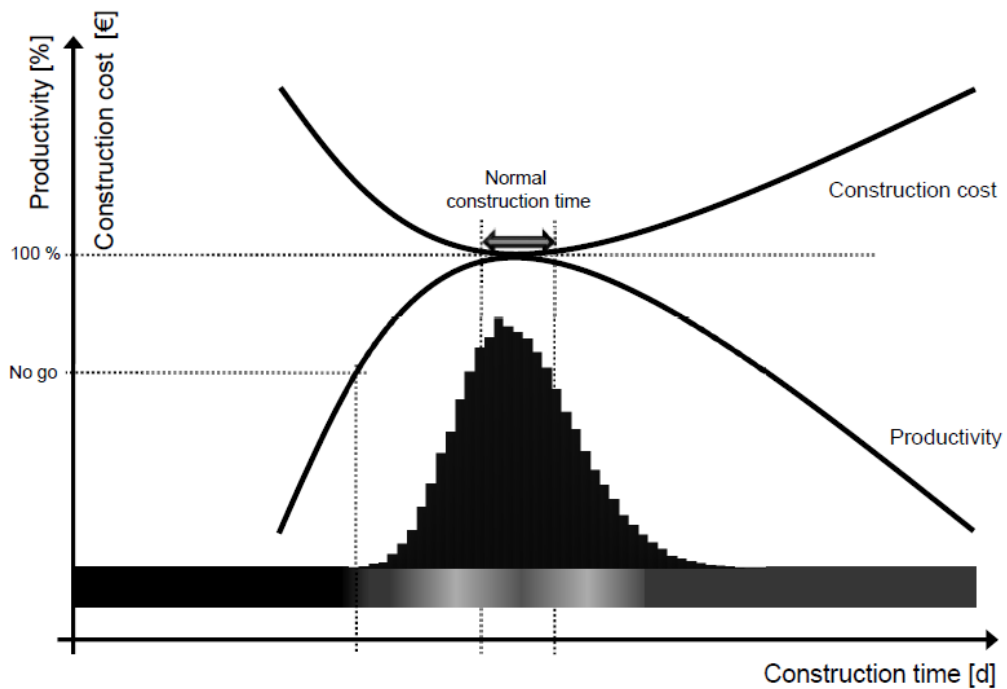


Figure 3: Relationship between construction time and costs; see Hofstadler (2014), p. 39

When determining construction time, the client usually considers limiting boundary conditions with an influence on site operations and management only to an insufficient extent, or not at all. These limiting factors result, for instance, from structural and operating conditions and have a major influence on the parameters that determine work output, such as the maximum number of usable workers or the maximum number of usable pieces of equipment.

A major issue in the context of calculating construction time is the linear nature of currently applied methods. In most cases, linear construction management-related correlations are used for the calculation process although these do not reflect reality. Any over- or underrun of thresholds or limits will lead to losses of productivity when capacities increase or decrease; these losses have a significant influence on calculation results. To accurately determine construction time, the various influences of productivity, such as limited available space for construction equipment, on production factors must always be considered.

Hruschka stresses that any calculation or optimisation of construction time must consider the mutual obstruction of the existing potential to prevent unrealistically short construction times. The construction time of a project cannot be shorter than permitted by the working capacity of the maximum installable transport equipment (Hruschka, 1969, p. 165).

Blecken states that the assumption of a deterministic production process leads to an oversimplification of the production model. Linear methods are chosen although most correlations of the combination of construction factors do not follow a linear pattern. He considers the additional application of stochastic methods to be a key tool to achieve significantly improved outcomes.

4.2 Definitions of construction time

The concept of construction time designates the calculated construction time prior to considering any buffer (assumed by the contractor). After determining construction time and considering the boundary conditions related to construction management and economics, the client should additionally account for a buffer to be able to compensate for any delays within its scope of responsibility.

Construction times are generally categorised as follows according to Hofstadler, 2014 (p. 57):

- **Extremely short construction time**
Construction time is determined in such a way that the number of workers and pieces of equipment to be utilised productively exceed the corresponding maximum values (= thresholds to losses of productivity) by 20%.
- **Very short construction time**
Construction time is determined in such a way that the number of workers and pieces of equipment to be utilised productively exceed the corresponding maximum values by 10%.
- **Short construction time**
Construction time is determined in such a way that the number of workers and pieces of equipment to be utilised productively represent the corresponding maximum values. Any disruption to the construction process may immediately lead to losses of productivity when adhering to the construction time target.
- **Normal construction time**
Construction time is determined in such a way that the number of workers and pieces of equipment to be utilised productively are 10% lower than the corresponding maximum values.
- **Long construction time**
Construction time is determined in such a way that the number of workers and pieces of equipment to be utilised productively are 25% lower than the corresponding maximum values.

5. Influence of construction time on productivity

The qualitative correlation between construction time and productivity has been outlined above and is also reflected in the current literature pertaining to construction management. The missing piece, however, is the quantitative correlation between productivity and construction time. It is important for all parties involved in the project to find out how productivity changes in the event of deviations from “normal construction time”.

5.1 Construction time and losses of productivity

How can reliable data be derived that quantitatively describe the correlation between construction time and productivity in a generic rather than project-specific manner? Any *ex post* analysis will be difficult because massive changes in the type and circumstances of work performance will have occurred at least to a certain extent, and additional works or services will have been commissioned, compared to the situation when the construction contract had originally been entered into. The originally agreed-upon construction project does no longer correspond to the actually completed building or structure. It is virtually impossible to arrive at a source-based differentiation to determine whether losses of productivity were caused by changes in construction time and/or changes in the type of work, the circumstances of work performance, or contracted additional works or services.

For this reason, subsequent studies were based on *ex ante* considerations as a practicable alternative.

To generate valid data, an expert survey was conducted at Graz University of Technology to determine the quantitative correlation between construction time and labour consumption rates, and thus productivity. A total of 35 experts working for construction contractors were interviewed (both from construction trades and industry; survey period from August 2012 to April 2013). Respondents had an average work experience of 17 years (minimum experience: five years; maximum experience: 43 years).

Experts were asked to estimate increases in labour consumption rates or losses of productivity to be expected if deviations from the optimal construction time occur from a construction management and economics perspective (first stage: questionnaire completion; second stage: discussion of the questionnaire with the expert). “Normal” construction time serves as a reference where production factors can still be utilised without losses of productivity.

Prior to analysing data from the expert survey more thoroughly, an exploratory analysis was carried out to get an overview of collected data. This step was necessary to check plausibility and distributions as well as to identify any outliers. Box plots of the variables were prepared as part of the analyses to graphically represent distributions. A box plot describes the location and spread of a distribution and indicates any existing outliers. Outliers and extremes may significantly distort arithmetic means depending on the distance from the box plot whisker. This phenomenon was prevented by applying the M-estimator method, which made it possible to move existing outliers/extremes closer to the “main mass” of data by assigning a lower weighting to them. Arithmetic means and M-estimators were used as a basis for preparing diagrams and trend curves for increases in labour consumption rates and losses of productivity.

The differences in the increases in labour consumption rates for shorter or longer construction times are reflected in the diagram shown in Fig. 4 to consider the influence of construction time at the costing stage or in the process planning phase. The x-axis represents the extension/shortening of construction time relative to normal construction time as a percentage whereas the y-axis shows the percentage increase in the labour consumption rate for reinforced concrete works.

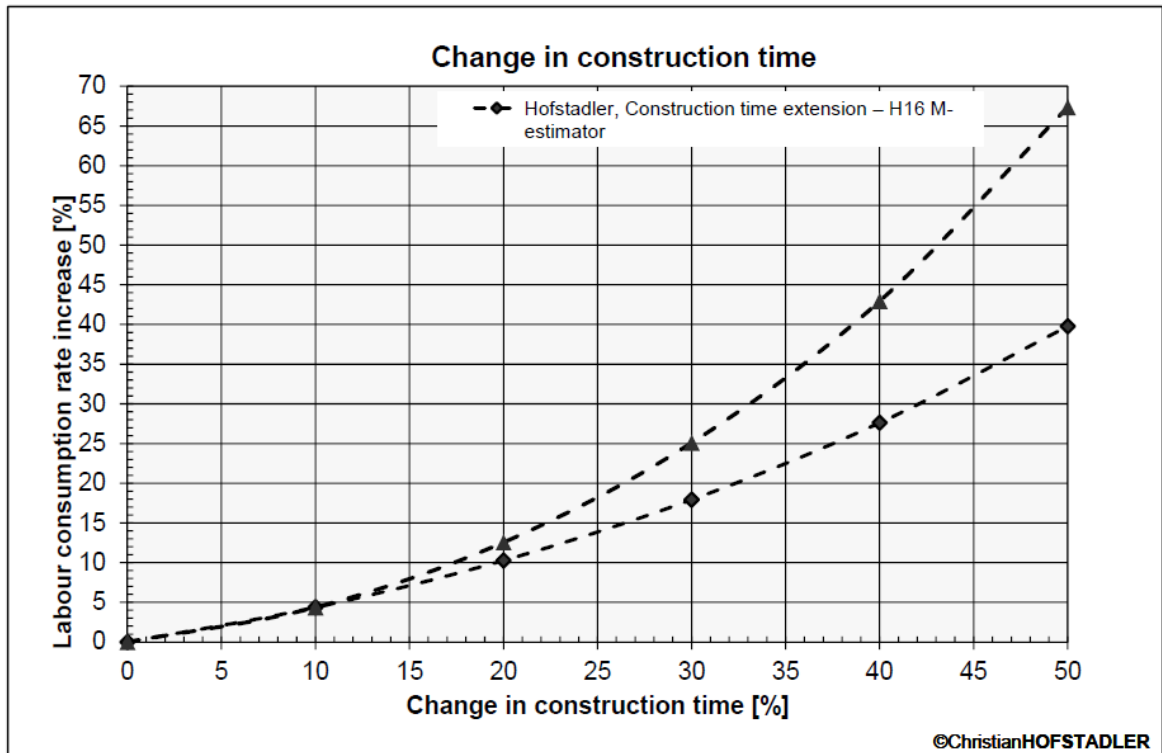


Figure 4: Trend curve for labour consumption rate increases – comparison between extension and shortening of construction time for reinforced concrete works (Hofstadler, 2014, p. 445)

The two curves are almost identical up to a 10% change in construction time. Only from the 15% threshold do the two curves deviate from each other. For instance, a 50% reduction/increase corresponds to a difference of about 27.6 percentage points. At a 50% shortening of construction time, the labour consumption rate increase amounts to about 67.4% and is thus 69.4% greater than in the case of construction time extension [= 67.4% * 100% / 39.8% -100%].

This comparison clearly demonstrates that a shortening in construction time is associated with greater labour consumption rate increases compared to an extended construction period. It is commonly known that shortened construction times lead to superimposed disruptions to productivity, particularly in the event of underruns of minimum available workspace and crane capacity.

There is a trend towards several different losses of productivity occurring simultaneously in the case of shorter construction times compared to construction time extensions.

5.2 Comparison with pertinent literature

The diagram shown in Fig. 5 compares the values cited in the pertinent literature to the results of the expert survey. This diagram represents the effects of shortened and extended construction times and the resulting losses of productivity. Oberndorfer, Petzschmann and Reister subsequently introduced generic limits and ranges for plausible productivity losses. Prior to using these limit values, care must be taken to ensure that the concept of productivity losses as interpreted by these authors is fully understood, as well as the calculation methods applied by them.

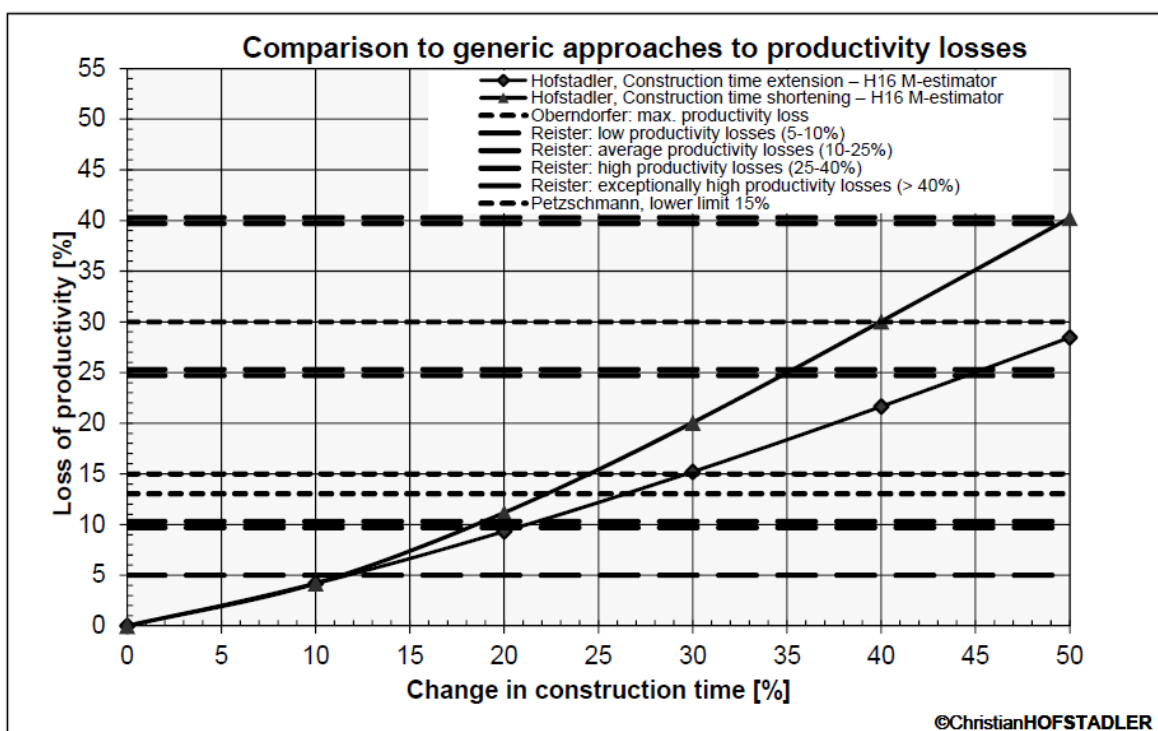


Figure 5: Trend curve of labour consumption rate increases – comparison between extension and shortening of construction time for reinforced concrete works (Hofstadler, 2014, p. 479)

The comparison with the limit defined by Oberndorfer shows that this limit is equivalent to the losses of productivity that would occur at a construction time shortening by about 22% and a construction time extension by about 27% as determined in the study conducted by Hofstadler.

In the event of simultaneous disruptions to the construction process, Petzschmann indicates a potential loss of productivity that ranges from 15% to 30%. The 50% productivity reduction according to Petzschmann is roughly equivalent to a 24% construction time shortening or a 30% construction time extension.

When considering the upper limit of 30%, the construction time shortening amounts to 40% whereas the construction time extension exceeds 50% (there is no point of intersection of the two curves in this case).

Reister considers ranges that cover the entire area of losses of productivity due to construction time extension or shortening. When considering a 45% construction time extension, it becomes apparent that the associated 25% productivity loss precisely coincides with the terminal average and initial high losses of productivity according to the categorisation applied by Reister.

For the 50% construction time shortening, the associated 40% loss of productivity precisely coincides with the terminal high and initial exceptionally high losses of productivity according to Reister.

The comparison of current results of the expert survey with the limit defined by Oberndorfer shows that this limit need not necessarily be applied, and that higher losses of productivity might occur. The limits stated by Petzschmann appear to lie within a plausible range. The ranges defined by Reister appear to be fairly plausible from a construction management perspective, depending on the extent of changes in construction time.

6. Conclusions

The correlation between construction time and productivity was shown both qualitatively and quantitatively on the basis of the new study published by Hofstadler. The effects on productivity and labour consumption rates to be expected if construction time is shortened or extended compared to the “normal” period were demonstrated. Related input data were collected directly in the expert survey. Arithmetic means were complemented by robust mean values calculated using the M-estimator method, which made it possible to systematically underweight any existing outliers and extremes in the calculation. The curves shown in the diagrams are thus very robust and reliable.

Any construction time that leaves sufficient room for considering all relevant construction management aspects will be beneficial for both parties to the contract. On the one hand, if the client specifies a normal construction time, this creates the preconditions for a construction process with very few disruptions. On the other hand, bidders can be highly confident in being able to utilise their production factors at their planned “normal productivity” level if a normal construction time is specified. Any disruptions can be overcome more easily compared to a construction process that had been disrupted already when work commenced due to an exceedingly short construction time.

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Productivity and performance measurement in the construction sector

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Abstract

Performance measurement has been applied systematically in many different sectors to drive improvements in productivity. Attempts have been made to establish measurements and benchmarking in the construction sector, but we still have not reached a situation where performance is measured systematically and consistently along the construction process. This paper reviews performance measurement theory pertaining to the construction sector to understand how performance is currently measured. Using participative workshops and interviews, we have mapped requirements of different stakeholders toward a performance measurement system. Based on literature and collected data, we outline issues to consider when attempting to develop further mechanisms for measurement. We also report briefly from a study to analyze different measurement and benchmarking systems to understand strengths and weaknesses of these initiatives. Based on this analysis, we have in Norway established a project to systematically test the CII 10-10 system to see whether it can meet measurement requirements at several levels in the construction sector.

Keywords: Performance measurement, benchmarking, productivity, construction sector

1. Introduction

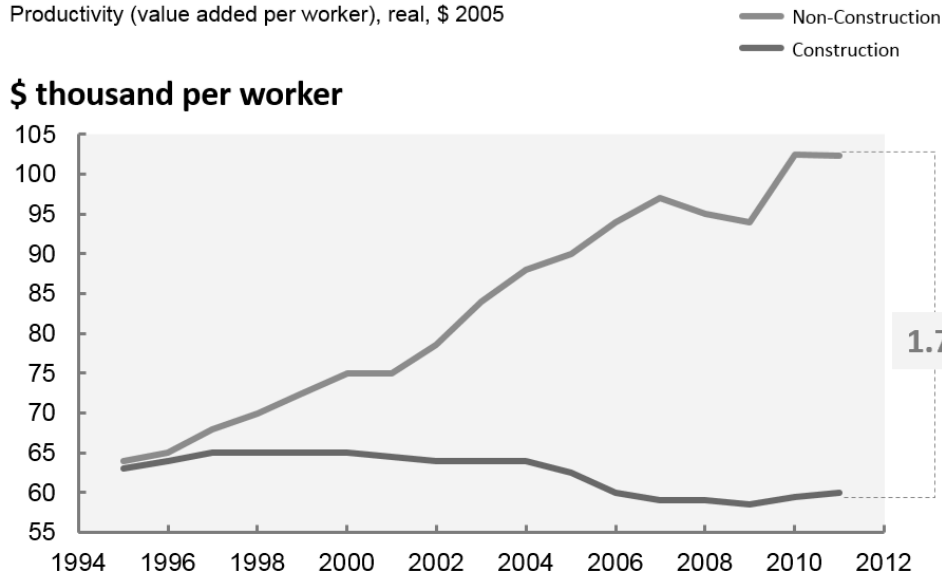
The word of mouth says that the construction industry around the world has great potential for improvement in productivity and performance, and this impression is supported by current research (Abdel-Wahab and Vogl, 2011, Ingvaldsen et.al., 2004). Multiple efforts have been launched to address this issue in recent years, but the main challenges for the industry are to document the real performance of the industry, understand where improvements are needed, and document whether improvement efforts have had the effect they were supposed to have. The fact is that the construction industry does not have a common measure, nor a common tool to measure, how productivity and performance improves or falls over time. This paper will argue that the construction industry should drop *productivity* as a measure and instead adopt *performance* measurement in order to support performance improvement efforts. The paper will also illustrate how a comprehensive performance measurement system should be constructed to address five different performance levels, and it will outline an ongoing effort to test the suitability of one performance measurement tool on the project level.

Today, productivity is the dominating indicator for performance in the construction industry. Productivity is the only measure available on an overall level in most countries, which is also the case in Norway, the country we have studied the most closely. The Norwegian Central Bureau of Statistics, SSB, provides annual productivity statistics. These statistics are based on the annual economic reports provided by all organizations registered doing business in Norway.

Figure 1 illustrates how productivity for the construction industry has declined, using the productivity in 1995 as a benchmark. By comparison, the productivity for non-construction has nearly doubled in the same time span. The statistics are, however, flawed and certainly not 100% reliable. First of all, not all organizations in the construction industry are represented in these statistics. Some organizations are included in other industries, such as oil and gas, since they have projects within both industries. Second, these figures are very high-level and fail to capture activity-level improvements. It is also a major problem that improvements that entail moving toward industrial production, i.e., off-site prefabrication of building modules, often has a double negative effect on construction productivity; this production is often transferred from construction to manufacturing in industry statistics. This means that the most productive activities are removed from the construction statistics, leaving the industry worse off than before the improvements were implemented.

Overview of productivity improvement over time

Productivity (value added per worker), real, \$ 2005



Source: Expert interviews; HIS Global Insight (Belgium, France, Germany, Italy, Spain, United Kingdom, United States); Input-Output Database

Figure 1 - Comparison of productivity improvement over time

Why, then, is it so hard to measure performance and get reliable measurements? Some of the answers are found in the characteristics of the industry itself. The construction industry comprises a large number of small construction firms, and a few larger contractors. A typical construction project consists of several small or medium-sized organizations temporarily working together, and they normally do not have any long-term relationship or partnership lasting longer than the duration of the project. They usually apply a contract model that does not give incentives for carrying out improvement efforts that will result in improved performance or increased value creation for other organizations. In other words, most improvement efforts are focused on increasing value for one single organization, and they do not necessarily find it interesting to help other organizations in the same project to increase their profits from that particular project. These characteristics results in sub-optimization and makes it harder to establish common measures and tools for performance measurement.

The long-term objective for the research project presented in this paper is to establish a set of tools that will support structured performance improvement efforts in the construction industry. The first step in this research effort is to select and test one tool for performance measurement in a range of Norwegian construction companies representing different actors in the project value chain. In addition, the first step will make sure that the experiences gained by each company is documented and shared between the companies.

2. State-of-the-art

According to Vogl and Abdel-Wahab (2015), in their review paper on the topic, there are not many papers that attempt to synthesize the existing literature in productivity research. Some attempts have been made (Yi and Chan, 2014; Dolage and Chan, 2014; Panas and Pantouvakis, 2010). Thus, it is difficult to find authoritative overviews of approaches and methods used to

measure productivity/performance in construction. The fact that the approaches employed originate from quite different academic fields further complicates efforts to provide such an overview.

Notice that we deliberately wrote “productivity/performance”, since these terms are often used either interchangeably or simultaneously (and then having somewhat different meaning) in publications. Many authors have discussed these terms, e.g., Page and Norman (2014), stating that “productivity measures how efficiently inputs are used to produce outputs” whereas “performance measures how well something achieves its intended purpose.” Takim et al (2003) defined performance measurement as “the regular collecting and reporting of information about the inputs, efficiency and effectiveness of construction projects... used to judge project performances, both in terms of the financial and non-financial aspects and to compare and contrast the performance with others, in order to improve program efficiency and effectiveness in their organizations”. These and many other definitions emphasize that performance is more detailed, with productivity often being seen as one aspect of performance.

Roughly, two main fields have contributed to the body of literature:

- Economics, discussing different ways to measure (and compare) productivity at a national and sector level.
- Operations management, looking at mechanisms to measure (and improve) performance at a business process and project level (both fields have also touched upon enterprise level measurements).

Under the economics approach, there are again two primary approaches; single-factor and multiple-factor models (Crawford and Vogl, 2006). The most widely applied single-factor model is the measurement of (average) labor productivity, which is typically applied by national statistics bodies in many countries. The calculation is done by dividing the aggregate output/value created by the labor input spent to produce the output. Multi-factor models attempt to explain productivity by considering factors beyond labor productivity, such as capital, technological progress, management, skills, etc. There are advantages and disadvantages of both approaches (ibid). Single-factor models require less data and allow cross-national benchmarking due to their widespread use, but at the expense of accuracy. Multi-factor models provide better insight through more fine-grained measurements, but require more data that can be difficult to collect. Extensive criticism has also been raised regarding the accuracy of high-level economics models, for example lack of suitable data (Allmon et al., 2000), that available statistics are unable to determine whether productivity in reality has decreased or improved (Rojas and Aramvareekul, 2003), and that a trend from on-site building to offsite manufacturing shifts this activity from the construction to the manufacturing sector (Haas et al, 2000). Irrespective of which economics model is applied, there is little relevance in terms of application at an operational level, in projects and companies and actors in the sector have therefore pursued alternatives (Harrison, 2007).

The operations management field offers bottom-up approaches, often termed “activity-level” measurement, based on measuring individual construction activities/processes. Equal to

economics-derived approaches, also here different mechanisms have been developed. Back in 2000, Allmon et al described how economics-based measurements could be replaced by activity-level measurements, but still relying on publically available statistics (Means' Building construction cost data, published by the R.S. Means Co. Inc. from 1960-1997 in the US and deflating costs using the Consumer Price Index). A different approach to operational performance measurement builds on so-called performance measurement frameworks, defined by Brown et al (1997) as "a complete set of performance measures and indicators derived in a consistent manner according to a forward set of rules or guidelines." According to Yang et al (2010), the primary frameworks applied in the construction industry are excellence models (e.g., the European Foundation for Quality Management excellence model), the Balanced Scorecard framework (Kaplan and Norton, 1996), and key performance indicators models (e.g., the KPI framework developed through the Construction Best Practice Program in the late 1990s (Lin and Shen, 2007)). As we show later, systems based on key performance indicators seems to have become more prevalent lately, as seen in the operational performance measurement systems currently available.

Goodrum et al. (2002) outlined some advantages of activity-level measurement over traditional aggregate measurement; by measuring output in real quantities (e.g., square area of building spaces or volume of materials) the issue of price indexes is eliminated, by measuring labor effort in terms of labor hours there is no need for using cost-index-based deflators, and it is easier to compare input and output changes over time. More importantly, while high-level productivity measurements at best capture a very few factors that affect the performance of the sector and its projects, there are a number of issues that affect the long-term viability of the sector. One set of such factors was proposed by Page and Norman (2014), factors such as building to quality the market needs, maintaining health and safety standards, developing and maintaining skills, adopting technology, innovating, etc. According to Harrison (2007), the key disadvantage of more detailed activity-level measurement is that assembling a complete sector view would require summing up all tasks in some manner, while it would be easy to omit tasks. And for all tasks, large amounts of high-quality data are required.

A last topic of relevance when it comes to activity-level measurements is at which level such measurements can target. Yang et al (2010) reviewed performance measurement studies undertaken in the construction sector and found three levels being discussed; the project level, the organizational level, and the stakeholder level. Of these, project level measurements came first (Lin and Shen, 2007), and encompassed a large numbers of different dimensions of performance, e.g., environmental performance, human resource performance, procurement performance, safety performance, technology innovation, etc. (many of these coincide with Page and Norman's factors (2014)). For enterprises in the construction sector, project-level measurements are valuable but the need for more aggregate company-level assessments induced efforts to measure performance at the organizational level (as reported by for example Bassioni et al, 2005). Such measurements cover both financial, as would be expected, and non-financial aspects (Bassioni et al, 2004). The third level, stakeholder-focused measurements, is arguably also important, as project success is ultimately judged by different stakeholders. Wang and Huang (2006) found that the owner's, supervisor's, and contractor's performances were

significantly related to the different criteria of overall project success. According to Yang et al (2010), there has been less work at this level of measurement.

We have so far briefly mentioned some more specific models/systems for performance measurement. To conclude this chapter, we outline in some more detail a selection of such models/systems, based partly on previous studies and partly on mapping undertaken ourselves. Going back to 2003, Takim et al reported from work to synthesize systems of measuring project performance in the United Kingdom, the USA, France, India, Hong Kong, Saudi Arabia and Malaysia. They found that these systems had different aims and focus of measurement; measuring both productivity and performance at a project level, assessing project viability, as well as targeting project quality. As far as we have been able to ascertain, few of these systems are still in use today, and we therefore conducted a renewed search for existing performance measurement systems. Table 1 lists the systems found that we judged to be most relevant for further investigation (we make no claim that our search was exhaustive).

Table 1: Overview of selected existing performance measurement systems

Performance measurement system	Country of origin	Measurement purpose	Data providers
Construction Industry Institute: 10-10 program	USA	Assess project performance at the end of each project phase through performance measurement and benchmarking	Project manager, project participants
Construction Industry Institute: General Program	USA	Detailed performance analysis after project completion using benchmarking	Project owner
Constructing Excellence: KPIzone	UK	Detailed performance analysis after project completion using benchmarking	Project owner
Benchmark Centre for the Danish Construction Sector: KPI System	Denmark	Evaluation of contractors in the form of a scorecard as a basis for more informed future choice of contractors and contractor improvement	Project owner
Performance Based Studies Research Group: Performance Information Procurement System	USA	Evaluation of contractors to allow selecting future contractors based on other criteria than price	Project owner
Project Norway: Health Check/Project Evaluation	Norway	Assessing performance throughout the life cycle of a project	Project participants
BRE: Key Performance Indicators for Construction Industry	UK	Performance measurement for a set of performance indicators that can be compared across projects or companies	Project participants
Customer satisfaction measurements	In use in different countries	Measurement of client/end-user satisfaction with the completed building	Client/end-user

We will refer to Table 1 and these systems in the discussion section of the paper.

3. Methods

The research presented in this paper has developed slowly, from an idea presented and discussed at a formal search conference in the Norwegian industry to identify ways to improve the performance of the sector. This turned into a research project, started in 2013, and currently has funding until 2017. The mentioned search conference prioritized performance measurement as one of six initiatives to be undertaken, as a means to truly knowing the current status, verifying whether improvement efforts have an impact, and undertaking industry analyses. The Norwegian Directorate for Building Quality (DiBK) funded an initial study to document the challenges facing the industry when trying to implement performance measurement and use the data to improve their performance. In turn, the first study laid the foundation for a secondary study, where the aim was to select and test one specific performance measurement tool in order to gain experience in both how that tool worked, what proper handling of the tool demanded of the organization using it, and how structured performance measurement should be carried out in practice. The main project started in August 2015, and will be carrying on until summer of 2017. The long-term objective for the whole portfolio of research effort is to develop a set of tools for performance measurement in the construction industry in order to support future efforts for continuous improvements in the industry.

A combination of different methods for data collection and data analysis formed the methodical framework for the research presented in this paper. Data collection was carried out using interviews, focus groups and expert panels. In addition, document studies were used as well as existing descriptions and documented experiences in using the different performance tools under evaluation. The representatives from the construction industry also participated in workshops where the findings were discussed and scrutinized. To a large extent, the same methods were used to analyze the data, especially focus groups, expert panels, and workshops. The integrity and validity of the data were ensured through triangulation, both researcher triangulation (using more than one researcher to analyze the same data) and the application of different types of data.

We have made some choices regarding methods, research approach and sample selection. First, we have not been able to identify and review a complete sample of tools available for performance measurement in the construction industry. Hopefully, our sample is satisfactory and encompasses the most frequently used systems that are publicly available. Second, the organizations involved come from the Norwegian construction industry. Still, our research has shown that there are many similarities internationally in the construction industry. Our findings could therefore be valid for other countries, even though this has not been the aim for this study. Finally, the research is still ongoing so our findings are not finalized yet, and the results should be reviewed in this perspective.

4. Results and Discussion

As chapter 2 showed, measurement of productivity and performance has been extensively discussed in relation to the construction sector. However, although many countries measure high-level productivity and several performance measurement framework and systems have been developed, we still have not reached a situation where performance is measured systematically and consistently along the construction process. As briefly discussed in chapter 3, as part of the research project aimed at investigating a possible new, operations-focused measurement system, we mapped the needs of different stakeholder groups in terms of measurement and measurement data. This led to the identification of five characteristics to consider when designing a performance measurement system (and based on these five characteristics, the subsequent development of a framework for evaluating a performance measurement system in terms of fulfillment of measurement requirements). The five characteristics are:

- *Level of measurement*; at which level of construction sector activity the measurements are undertaken, as discussed by Yang et al (2010) and treated in more detail below
- *Who undertakes the measurements*; who is responsible for collecting the measurement data, e.g., the project owner, engineering consultants, contractors, authorities, external actors, etc.
- *Dimension of performance measured*; the performance measurement literature suggests a wide range of aspects of performance that can be measured, spanning dimensions like time, cost, quality, flexibility, SHE, communication, innovation, learning, environmental impact, and ethics
- *Project phase targeted*; construction projects can be divided into a number of different phases and the measurement needs will typically vary across phases (this is for example evident in how CII has chosen to link the 10-10 performance measurement and benchmarking system to five project phases)
- *Type of project/building/infrastructure*; not surprisingly, we found that the usefulness of the selection of performance indicators applied vary from project type to project type, e.g., office building, laboratory facility, rail line, etc.

Regarding the first of these dimensions, the sector/activity level addressed by the measurements, for activity-level measurements, Yang et al (2010) identified three levels; the project level, the organizational level, and the stakeholder level. In our mapping of measurement stakeholder groups, we found five distinct groups that also logically correspond with measurement levels:

- *The country level*; by this, we think of the economics-type measurements undertaken at a high level of aggregation, typically for the whole construction sector of a country. This level of measurement has many stakeholders with highly differing needs for measurement, but some key measurement purposes can be to demonstrate the importance of the construction sector in society, promote the reputation of the sector, improve competitiveness, feed national and supranational statistics to allow tracking of trends and benchmarking.
- *The project/value chain level*; we have combined the terms *project* and *value chain* to clearly communicate that this level addresses whole projects and their (often multiple) value chains that contribute to delivering the project (this corresponds to the project level

identified by Yang et al (ibid). To measure and promote better performance of projects, this level of measurement must be able to assess the performance across individual actors to determine how well they collaborate to perform the project. Such measurements should provide detailed insight into the performance of the projects, especially which performance drivers affect overall performance, as well as stimulate behavior that create win-win situations.

- *The company/organizational level*; meaning the individual (private) company or (public or non-profit) organization participating in the construction project (corresponding to the organizational level discussed by Yang et al (ibid). Many measurements at this level are required by authorities or for accounting purposes, but other measurements that aggregate results from the organizations' projects are also important.
- *The construction process level*; academic sources and practitioners apply different terms to the lowest activity level of a construction project, e.g., construction processes, business processes, work processes, and we refer to these processes, for example land acquisition, production of drawings, electrical installation, etc. These measurements serve several different purposes; provide a platform for fact-based improvement efforts, promote an end-to-end view on processes to counter sub-optimization, assess effects of changes in processes, etc.
- *The user level*; this last one is not as clear a "level" as the other four and could even be argued is a phase of the project rather than a level of measurement. What we mean here is the users' perceived performance of the project and its deliverables, an important aspect of performance often overlooked in existing literature, and one that can only be measured after completion of the project, ideally even only after some period of use, this indicating that this is a matter of project phase. However, we could also argue that this is a singular instantiation of the stakeholder level outlined by Yang et al (ibid), and we have therefore chosen to include it as the fifth level. The purpose of these measurements are to assess whether the delivered building or infrastructure fulfills its purpose (usability), to understand the long-term life cycle performance of it, evaluate user satisfaction, etc.

Put together, the five characteristics of a performance measurement system can be construed as spanning a five-dimensional matrix. Every single cell in such a matrix would represent a unique measurement context to be populated, and in an absolutely complete performance measurement system, each cell would be populated with at least one performance indicator serving a unique purpose. In reality, the different combinations carry highly differing relevance, and a "complete" measurement system would be extremely complicated and contain many measurements of little interest. To identify cells of the matrix that seem to have the highest potential for delivering relevant measurements, we defined a set of criteria to use when mapping measurement requirements among sector stakeholders:

- Is there a measurement need and purpose?
- Is there sufficient availability and quality of the data required?
- How much effort and cost will be involved in establishing the measurement?
- Do other established performance measurement systems undertake this measurement, thus allowing benchmarking?

Regarding the issue of data availability and quality, it is obvious that any performance measurement system and regardless of which exact performance indicators are defined, will require a fair amount of performance data. An effective construction sector system should strive

to exploit lessons learned from other sectors when it comes to data collection, where we see that there a number of “archetypes” of measurement approaches that pose different opportunities:

- Manual or automatic harvesting of data from public records, e.g., industry statistics, accounting systems, license data, etc.
- Automatic data collection from different sensors or sources. This is an area with a large potential for effective data collection. Approaches can include collecting measurements from sources like moisture sensors, drone-mounted cameras, scanners, step counters on smart phones, etc. See Akinci (2015) for a presentation of some opportunities different technologies provide for data collection.
- Exploiting so-called crowdsourcing where large numbers of users cooperate to populate databases with relevant data. An example of this approach is the Danish construction scorecard system where public sector project owners score suppliers according to a number of performance dimensions, where this data is later made available to other project owners.
- Establishing a structured database for benchmarking, where users are encouraged to input performance data by allowing them to compare their own data against others'. Several of the performance measurement systems listed in Table 1 build on this principle.

Irrespective of the chosen performance measurements and which approach is used to collect the performance data required, the purpose of any measurement effort is obviously to give users of the system new insight. A fundamental analysis is to identify relationships between so-called *outcome measures/result indicators* and *performance drivers* (Kaplan and Norton, 1996). Result indicators say something about the end performance level of an activity or process, for example quality expressed by user satisfaction or warranty costs, productivity expressed as the portion of craft hours spent on value-added activities, or safety expressed as recordable incidents or time away due to injuries. These are the results of different performance drivers, characteristics about how the processes are designed or other contextual factors, for example the level of involvement of building contractors in the engineering phase, degree of prefabrication, distance between storage and work area on site, etc. Important insights can be gleaned from investigating whether changes in results indicators can be explained by differences in performance drivers, as this can help identify good practices that will improve performance.

The identified characteristics of performance measurement systems and assessment criteria presented here can be combined to either evaluate existing systems or as guidelines when designing a new system. In the end, the criteria we developed and that were used to evaluate the systems mentioned in Table 1 are those shown in Table 2 below. The table also shows our assessments of each system, and we underline that these were subjective assessments made considering our requirements for a measurement system to be pilot implemented in Norway.

The conclusion was that there is not one single system that meets all requirements. However, we found that the CII 10-10 system seems best suited for adaptation into a national construction industry system for Norway as it had the best score of all the systems presented in Table 2. This system will be tested in a number of companies and at the aggregate level during the next two years.

The 10-10 system provides benchmarking of project performance based on anonymously surveying project management team members and collected facts on project progression. 10-10 surveys by phase instead of at completion, and uses five distinct but overlapping phases (front-end planning/programming, engineering/design, procurement, construction, commissioning/start-up) using simple statement-based questions. In addition, the system uses ten leading indicators (input measures) and ten lagging indicators (outcome measures) to collect facts, hence the name 10-10. A project benchmarks its performance with other projects in the same phase, and it is possible to see how the performance of the project develops during the project life cycle. A more thorough description can be found on the CII web site¹.

5. Conclusions

This paper reports from a study undertaken on the use of performance measurement in the construction sector, a study that addressed several issues that need to be resolved for such measurements to be meaningful and have an effect. Previous studies have investigated different levels measurements can be undertaken at, typically distinguishing between country/industry and project/activity level measurements. We have found that in order to provide a comprehensive set of measurements that serve a number of different purposes, an extensive measurement system is needed that addresses five levels; the industry/sector level, the company level, the project level, the process level, and the user “level”. Furthermore, the range of issues targeted for measurement must also be expanded, from pure labor productivity assessments and a narrow set of project level factors to a wide set of performance indicators that can be used to facilitate understanding, improvement, and aggregation to higher levels.

Having looked into existing measurement systems and evaluated these against a set of requirements, it seems clear that there is no extant system that meets all requirements. It is probably not likely that one unified system ever will exist, but we see that it is crucial that if several systems must be used, these must be linked and allow aggregation of data across the different measurement levels.

In the Norwegian construction sector, we have found the CII 10-10 system to be the one existing system that promises to meet the most of our requirements. Together with about twenty organizations in the industry, we will initiate extensive testing of this system to see how well it manages to serve both process and project level improvement efforts, analyses into performance drivers and their effects, as well as industry-level statistical needs. We will report from this work in future papers, and in the mean time hope other countries experiment with other measurement models and systems so that we jointly can move the industry forward.

¹ <https://www.construction-institute.org/benchmarking/10-10.cfm?section=pa>

Table 2: Evaluation of existing performance measurement systems (* = criterion met, (-) = criterion partly met, _ = criterion not met, N/A = not relevant)

Criteria	Systems																
System availability, can be put to use without extensive adaptations	*	CII 10-10	(-)	CII General program	(-)	Constructing Excellence KPIzone	(-)	Benchmark Centre for the Danish Construction Sector KPI System	*	Performance Based Studies Research Group PIPS	(-)	Project Norway: Health Check/Project Evaluation	*	CCI KPI Engine	*	Customer satisfaction measurements	*
User-friendliness	*	*															
Data presentation, how easy is it for users to comprehend presented data	*	*	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Ease of extracting data and analyzing the data to create insight into project/company/industry	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Ability of the system to handle a large number of users	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Potential to be used by most actors within the sector	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Likelihood that the system will be available in the long run	*	*	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Usage of existing data to minimize data collection needs	*	*	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Quality check/verification of data before used in analyses	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Ability to deliver new insight through data analysis	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Usefulness at different levels of measurement	*	*	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Possibility for aggregating data	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Overall assessment of ability to satisfy requirements for a measurement system	*	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)

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The interplay between formal and informal networks in construction projects

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Abstract

The primary aim of this research is to examine the interplay between formal and informal networks in construction project-based organisations (PBOs), with a view to understanding its impact on project performance. PBOs, as an organisation form, have been widely adopted to organise works in various industries, especially construction, information communication technology, automobiles, film-making and the media, and so on. Previous studies have recognised the importance of formal institutions (e.g. hierarchies, contracts) while that of informal institutions (e.g. social network, culture) has yet to be well documented, or at most, merely treated as a supplement to the formal ones. This study goes beyond that by arguing that the interplay between the formal and informal institutions has a significant effect on project performance. It does so by conceptualising PBOs as social networks, including formal and informal networks, which are representations of the formal and informal institutions, respectively. Three PBO case studies in the construction industry are conducted. With the help of Social Network Analysis (SNA), the graphical and mathematical presentations of both formal and informal networks in three PBOs are explicated. It is found that the greater the extent of “fit” between the formal and informal networks/institutions of a PBO, the better the project performance will be. The research contributes to the knowledge body in two folds: (1) methodological innovation through integrating PBO, SNA and institutional analysis, and (2) examination of the impact of interplay of formal and informal networks on project performance.

Keywords: Project-Based Organization, Social Network Analysis, Fit, Construction

1. Introduction

PBOs as an organisation form have been widely adopted to organise works in various industries, especially construction, information communication technology, automobiles, film-making and the media, and consulting and professional services. According to Sydow et al. (2004), PBOs refer to a variety of organisational forms that involve the creation of temporary systems for the performance of project tasks. Here, a project can be defined as a temporary organisation to which resources are assigned to undertake a unique, novel and transient endeavour (Turner and Miller, 2003). Winch (1989) classed PBOs as 'intra-firm' and 'inter-firm' organisations. Intra-firm PBOs, e.g. in-house projects, are still under the ambit of a single economic unit or firm. The operations of intra-firm PBOs are normally governed by hierarchical relations. By contrast, inter-firm PBOs are a coalition of multiple firms with divergent economic and social interests (Winch, 1989). Project governance in inter-firm PBOs is mainly through contracts, and more recently has seen a shift of focus to informal institutions such as relations, trust, and culture.

The advantages of PBOs include less inertia associated with permanent organisations, better processes, higher output quality, increased ability to respond to customers' needs and innovation in collaboration with clients and suppliers. However, the downside is that PBOs bring new challenges to knowledge management, human resource management, and strategic management. Researchers have endeavoured to explore how to maximise the advantages while overcoming the downside of PBOs.

The construction industry has been consistently used as a typical institutional setting for inter-firm PBOs research and practice. It is an industry in which the forms of PBO have long been taken to be the norm across a significant swathe of activity (Morris et al., 2011; Bresnen et al., 2004; Gann and Salter, 2000; Winch, 1989). Without PBO, the industry may not have developed so many roads, bridges, offices, housing projects and the like, which are instrumental in influencing human health and social behaviour as well as cultural identity and civic pride (Pearce, 2003). The industry is said to be the largest industry employer globally (WTO, 1998), accounting for around 10% of the world's GDP, and yielding an output of approximately US\$ 4.8 trillion per annum (Flanagan et al., 2007). Nevertheless, the industry has also received its fair share of criticism for its widespread problems such as late delivery, budget overruns, and lacklustre performance (Li et al., 2009). For example, in 2004, the Construction Industry Institute of the US estimated that 57% of money spent on construction in the USA is non-value-added and is therefore wasted (Eastman, 2008).

MacLeamy (2008) attributed the above problems to a fatally flawed system: design, bid, and build (DBB). Under the DBB system, professionals such as architects, engineers, surveyors, and contractors are separately contracted to do a parcel of the work. Although under the same umbrella as PBOs, they are not necessarily involved in the whole project lifecycle. As such, they do not always work together efficiently and, in fact, can have competing interests (MacLeamy, 2008). This is well known as the fragmentation and discontinuity that exists in construction PBOs. With such structural problems, it is not uncommon to see issues such as risk-aversion, short-termism, silo thinking, lost information, and ineffective communication. It

is no exaggeration to say that the construction industry has witnessed almost every downside that a PBO could have. Responding strategies have been explored, e.g. encouraging communication (Dainty et al., 2006), promoting relational contracting, emphasising the importance of culture and trust (Rowlinson and McDermott, 1999), and advocating design and build integration (Walker, 2007) and public private partnership (Li and Akintoye, 2003).

There are many formal institutions of PBOs in the construction industry, such as ownership, financing modes, contractual relationship, outsourcing and sub-contracting, strategic alliancing, etc. These formal institutions have a great effect on the project performance. While recognising the importance of formal institutions associate with a PBO (e.g. organisation structure, hierarchies and authorities, and contractual arrangement), researchers increasingly start to examine the importance of informal institutions. For example, Pauget and Wald (2013) reported a vivid case of a French hospital construction project, in which relational competence in complex temporary organisations was investigated. While formal institutions define the “normative system designed by management” or the “blueprint for behaviour” (Scott, 1981), informal institutions define the actual behaviour of players. Informal institutions are largely shaped by soft factors such as players’ mindset, trust, Guanxi, or project manager’s charisma. They may or may not be in line with the formal institutions with the constraint of the specific PBO environment. Krackhardt and Hanson (1993) metaphorically describe the informal network is “the central nervous system driving the collective thought processes, actions, and reactions of its business units”, and must be matched with the formal network, which is the skeleton of an organization, only by that the productive engine of the organizations can be fully steamed. However, as a whole, the importance of informational institutions in construction PBOs has not been well documented. Too often, they are treated as exogenous factors, which only passively responded to alternative formal institutions (Zenger et al., 2002). They go further and theoretically discussed the interplay of formal and informal institutions in organizations, and argued that it would have significant impact on the organizational performance (Zenger et al., 2002). Nevertheless, empirical studies on the interplay in construction PBOs are few and far between.

The aim of this research is to examine the interplay between formal and informal networks in construction PBOs, with a view to understanding its impact on project performance. The research question of this study is “how does the interplay of formal and informal networks associate a PBO affect project performance?”, and the main research hypothesis is as H: *The greater the extent of “fit” between the formal and informal institutions associated with an innovative procurement system, the better the project performance will be.* The article is organized in the following way. Subsequent to this introduction section is the methodology, whereby construction PBOs are conceptualised as social networks, including formal and informal networks, which are representations of the formal and informal institutions, respectively. SNA is then employed as the main analytical tool, followed by the description of three case studies. Then, the results of data analyses are presented and discussed. Finally, conclusions, implications and limitations are provided.

2. Methodology

A mixed method comprising of case study, interview, survey/questionnaire, archival study, field study, and social network analysis are integrated to answer the research question. There are many possible ways to collect the data for mapping the SNs, such as the use of questionnaires, interviews, participant observations (Scott, 1991), and ethnographic methods (Hartmann and Fischer, 2009). However, these methods often rely heavily on personal judgment of the informants and are very time-consuming. This study collected relational data of informal institutions, which is often “off-the-record”, thus requires considerable skills in interviewing, ethnographic studies that can interrogate real relations from those relations bearers. In this study, the information of informal networks occurred in workplace of a PBO was collected to characterize the informal institutions. Particularly, this study introduces a novel method, which is able to develop a set of SNs from timesheets. Case studies of three PBOs set the framework and boundary for this study. Interviews, survey, archival study and field study are the direct methods used in the data collection process, while SNA and related correlational analysis are employed in the data analysis.

2.1 Theoretical foundation

The relationships amongst the project team members in a PBO can be understood by treating them as a ‘socio-technical system’, which is a systems approach to complex organizational design that recognizes the interaction between people and technology in workplaces (Tavistock Institute, 1966). However, Winch (1989) argued that it has only limited analytical use in construction PBOs. Schweber and Harty (2010) thus proposed the “socio-technical networks” to examine the relationships. Notably, researchers have conceptualised PBOs as social networks (SNs), which consist of a finite set or sets of actors and the relation of relations defined on them (Wasserman and Faust, 1997). Loosemore (1998) investigated interpersonal relationships in PBOs under crisis conditions using SNA. Nohria and Eccles (1992) asserted that all organisations are SNs and therefore need to be analysed in terms of networks of relationships. Following this line of thought, Pryke (2005; 2012) suggested that a construction PBO can be represented as a multi-layer of interdependent networks. Chinowsky et al. (2008; 2010) also clearly stated that project organisations are SNs. Drawing upon these theories, it is appropriate for this proposed study, by emphasising the embeddedness of project management in a social context, to take the theoretical stance that PBOs are SNs.

If we accept that a PBO is an SN, then our understanding of the effects of formal and informal institutions interplay in a construction PBO can be related to the analysis of the network by using the established SNA approach. As an academic discipline introduced by Moreno (1960), SNA has matured over the past decades (Wellman et al., 1988). It is concerned with the structure and patterning of relationships over time and its purpose is to examine how the relationship structures impact behaviours, and to identify both their causes and effects (Wasserman and Faust, 1997; Scott, 1991). SNA is a new “language” to represent and understand PBOs (Pryke, 2012). Mead (2001) underscored the value of SNA in visualising project teams. The translation of PBOs into SNs also enables SNA to be applied, particularly its

mathematical and sociological methods, to study project relationships in a manner that will inspire both academic and practical interest (Hughes, 2012).

2.2 Social network analysis

The collected data include data about formal networks and that about informal networks. The former mainly embrace contractual relationship and organizational structures, while the later contains self-reporting of the real-life communication and/or archival records of the work-related interactions. Data collected in all the three case studies are preliminarily edited, coded, and translated into SNA language. As shown in Figure 1, according to the information of the links, the collected data about formal networks are converted into adjacent matrix, which is the SNA data input format used in *Ucinet* and *R*. Similar conversion method can be performed based on the collected data about the communication information. The validation of the networks is crossed checked and rectified through further enquiry by email, phone or face-to-face talk.

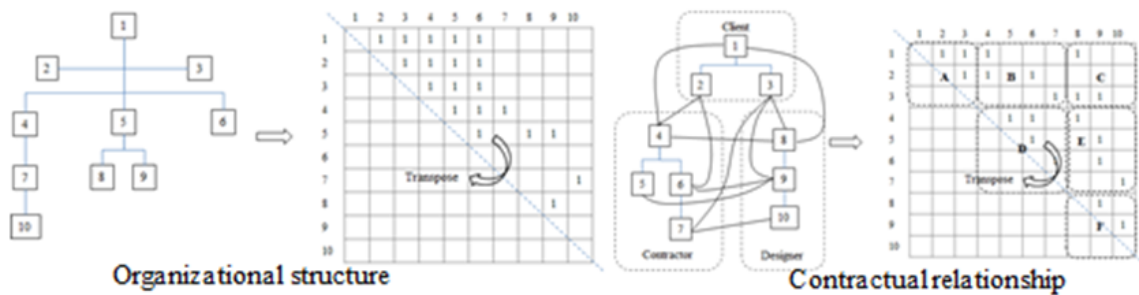


Figure 1 The illustration of the method to converse the collected data into adjacent matrixes

When the data are ready, it comes to the further data analysis, which constitutes of two phases. The first phase is the graphical and mathematical presentation of social networks to characterize the formal and informal institutions. SNA is carried out through the SNA software *Ucinet* and *R*. The visualization function in the software is able to convert the adjacent matrixes into various graphs of networks. The key actors, network density and clusters can be observed within the vivid images. It helps the researchers to get a big picture of the networks, and to gain the preliminary sense of the patterns of the data. The mathematical presentation of the social networks includes a set of metrics, e.g. network density, diameter, average path length, degree / closeness / betweenness centrality, clustering coefficient, etc. The metrics can be utilized to reveal the hidden patterns and trends in the data. Particularly, the physical meanings of the metrics, as explicated in Table 1, will be analysed and discussed in the rich context of the three case studies.

2.3 “Fit” between the formal and informal networks

To measure the fit of formal and informal institutions surrounding a PBO, a simple instrument was developed based on two main principles. First is the complementary/rival nature of a network metric. If a network metric is complementary, it means that an increase in the fit index

leads to higher level of fit; if rival, an increase in the fit index leads to lower level of “fit” and it is expected to result in poorer project performance. Second is the benchmark, as set by the metrics of formal social networks. Here, the closer the fit index value is to 1.0, the more similar the formal and informal social networks are. In the context of PBOs, “fit” can be understood through the discrepancy between informal and formal institutions.

The fit index of a metric X at the individual level is assigned as the proportion of the average value of X in the informal network, denoted as $Average (X^I)$, and that in the formal network, denoted as $Average (X^F)$. The equation is shown as below:

$$Fit\ index = \frac{Average (X^I)}{Average (X^F)}$$

The fit indexes of the metrics at the network level are calculated according

$$Fit\ index = \frac{Informal}{Formal}$$

Where, given a particular metric X , Informal stands for the value of X of the informal network and Formal stands for the value of X of the formal network. Two main principles behind when the author developed the concept of fit index are as follows:

1) The nature of complementary of a metric

The value of the fit index for a given SNA metric is expected to be closer to 1 in order to achieve a better project performance. By saying complementary, it means that the increase of the fit index leads to higher level of fit. Similarly, a fit index is rivalry means the increase of its value is expected to result in a poorer project performance.

2) Benchmark: the metrics of formal social networks are set as the benchmark.

As shown in the equations, the fit of formal and informal institutions are measured by the comparison of the formal and informal social networks. The closer the value of a fit index is to 1, more similar the formal and informal social networks are.

The level of fit between the formal and informal institutions is interpreted by Discrepancy of Fit (DoF) between the designed formal network and the actual informal network, which is equivalent with the extent of being close to 1.0. The discussion applies to both the SNA metrics at network level and individual level. Mathematically, DoF is measured in Equation 5.3, which is the same as Equation 4.2. Given a metric, the value of DoF is usually larger than 0, unless there is a perfect fit between the formal and informal networks in terms of the metric.

$$DoF = |Fit\ index - 1|$$

According to extensive literature review, the metrics selected for this study are grouped into *network level metrics*, including network density, diameter, average path length, global clustering coefficient, and *individual level metrics*, including degree / closeness / betweenness

centrality, and local clustering coefficient. Totally, eighth metrics are employed to develop the main hypothesis (*H*) into eight respective sub-hypotheses, where the extent of “fit” in (*H*) is measured the metrics.

2.4 Case studies

The description of the three case studies is shown in the Table 2. Project Alpha is an infrastructure project in Hong Kong with four separated contracts. It is a complex construction project, with a huge amount of financial investment of about 36 billion HKD. Project Beta includes two public housing projects done by the same government department in Hong Kong. Project Gamma is a building project in Germany, with a relatively small financial investment of 180 million HKD. This project is the only one that is private funded. The network boundary of SNA is set to be active PBOs in the three case studies respectively (for the time being of data collection), with the actors the main project participants and the links the formal or informal “interactions” aforementioned above.

Table 2 Description of three case studies

<i>Project Ref</i>	<i>Alpha</i>	<i>Beta 1</i>	<i>Beta 2</i>	<i>Gamma</i>
<i>Project type</i>	<i>Infrastructure</i>	<i>Public Housing</i>	<i>Public Housing</i>	<i>Building</i>
<i>Duration</i>	<i>8 years</i>	<i>3 years</i>	<i>4 years</i>	<i>21 Months</i>
<i>Financial size</i>	<i>36,0000 Million HKD</i>	<i>470.0 Million HKD</i>	<i>610.4 Million HKD</i>	<i>180 Million HKD</i>
<i>Financing method</i>	<i>Government appropriation</i>	<i>Government appropriation</i>	<i>Government appropriation</i>	<i>Private fund</i>
<i>Physical size</i>	<i>4.5 km long trunk road, 3.7 km long tunnel and 3 km approach roads</i>	<i>11,950 m²</i>	<i>11,871 m²</i>	<i>14,800 m²</i>

3. Data analysis and results

There are totally 4 PBOs in the three case studies, 1 for Case Alpha, 2 for Case Beta, and 1 for Case Gamma. The main outcome of preliminary data processing mainly is the adjacent matrixes for both formal and informal networks. The two matrixes are imported into *Ucinet* to have the network visualization and into R to calculate the SNA metrics. Figure 2 is the graphical presentation of the formal and informal networks in Case Beta 1. The size of a node is proportional to the node’s degree, and the displace rule of the two graphs in Figure 2 is trying to highlight the “important” actors in the middle. Hypothetically, the formal network shall set up the basic structure for the informal network, since the former shows the designed working relationships among actors within the PBO, while the later one is the actual interactions occurred during the project delivery process.

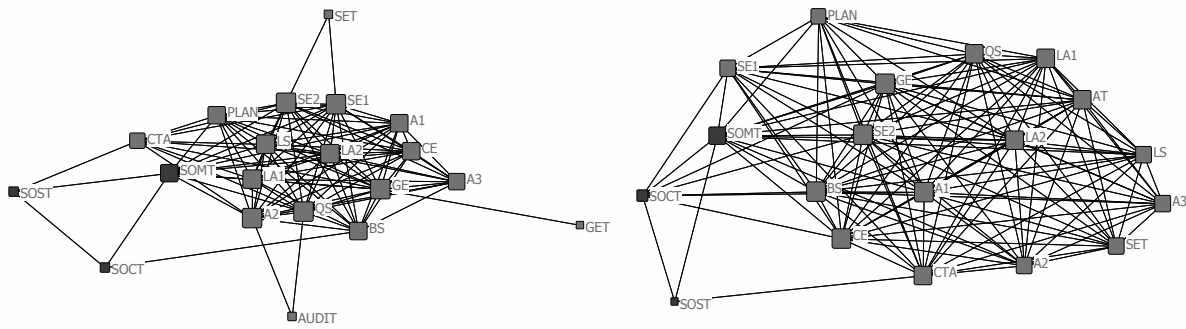


Figure 2 The graphical presentation of the formal and informal networks of Case Beta

The ‘fit’ of formal and informal networks will be examined at two levels, namely, individual level and network level. The former concerns the investigation of fit of formal and informal networks surrounding an individual, e.g. the degree centrality, and the clustering coefficient, while the latter concerns the overall fit between the formal and informal networks, e.g. density, average path length, and diameter. It is expected that to do so will allow a comprehensive understanding of the interplay from both a micro and macro perspective. The fit index of a metric X at the individual level is assigned as the proportion of the average value of X in the informal network, to that in the formal network. The fit indexes of the metrics at the network level are calculated as the proportion of the value of the metrics in the informal network to that in the formal network. The results of the SNA metrics of the four PBOs are presented in Fig. 3 and Table 2, respectively.

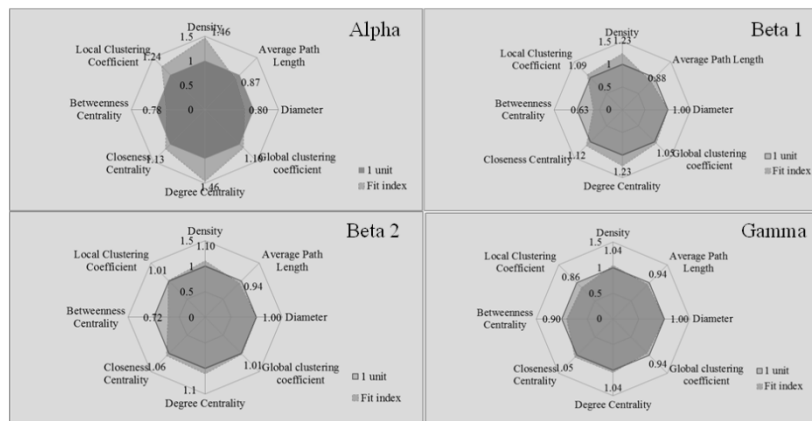


Figure 3 The spider diagrams of the fit indexes in the four PBOs

Table 2 A summary of DoF and project performance

		<i>Alpha</i>	<i>Beta 1</i>	<i>Beta 2</i>	<i>Gamma</i>	
<i>DoF</i>	<i>Network level</i>	<i>Density</i>	0.46	0.23	0.1	0.04
		<i>Average Path Length</i>	0.13	0.12	0.06	0.06
		<i>Diameter</i>	0.2	0	0	0
		<i>Global Clustering Coefficient</i>	0.1	0.05	0.01	0.06
	<i>Individual</i>	<i>Degree Centrality</i>	0.46	0.23	0.1	0.04

	<i>level</i>	<i>Closeness Centrality</i>	0.13	0.12	0.06	0.05
		<i>Betweenness Centrality</i>	0.22	0.37	0.28	0.1
		<i>Local Clustering Coefficient</i>	0.24	0.09	0.01	0.14
<i>Performance</i>		<i>Time</i>	4.00	4.25	4.50	4.10
		<i>Cost</i>	3.75	4.25	4.50	3.86
		<i>Quality</i>	4.13	4.25	4.50	4.44
		<i>Working Environment</i>	4.00	4.00	4.00	4.89
		<i>Health & Safety</i>	4.00	4.50	4.50	5.00
		<i>Total Performance</i>	3.96	4.25	4.43	4.36

The data about the project performance of the four PBOs were collected through secondary empirical data and subjective assessment. The secondary empirical data from archival documentations and published materials are preferred to objectively measure the project performance and soliciting project staff and asking them to report their self-perception on project performance is also adopted as an alternative data collection method. After the collected data were edited, cross-checked, coded and standardized, a correlational analysis is carried out to discuss the interplay of the formal and informal networks and its impact on the project performance of the PBOs, followed by the qualitative discussions. The correlational result is shown in Table 3.

Table 3 Correlation between the fit indexes of the SNA metrics and project performance

<i>DoF of SNA metrics</i>	<i>Time</i>	<i>Cost</i>	<i>Quality</i>	<i>Work-En</i>	<i>H&S</i>	<i>TOTAL</i>
<i>Density</i>	-0.27	-0.59	-0.40	-0.13	-0.32	-0.96
<i>Average Path Length</i>	-0.60	-0.35	-0.76	-0.23	-0.37	-0.87
<i>Diameter</i>	0.17	-0.84	-0.07	0.20	0.00	-0.93
<i>Global Clustering Coefficient</i>	0.11	-0.89	-0.41	0.54	0.38	-0.90
<i>Degree Centrality</i>	-0.27	-0.59	-0.40	-0.13	-0.32	-0.96
<i>Closeness Centrality</i>	-0.63	-0.30	-0.72	-0.32	-0.46	-0.84
<i>Betweenness Centrality</i>	-0.91	0.62	-0.50	-0.94	-0.94	-0.03
<i>Local Clustering Coefficient</i>	0.22	-0.94	-0.30	0.60	0.44	-0.88

Note: the closer DoF to 0, the less discrepancy between the designated formal network and the actual informal network, i.e. the fitter.

The results in Table 3 show that the *DoF* of density has a negative relationship with the total project performance, with the correlational coefficient of -0.96. Furthermore, the negative relationship is confirmed in all five aspects of project performance. Therefore, H is accepted.

4. Discussions

This study explored the interplay of formally designed working network and the actual network of informal interactions. By using SNA, the graphical and mathematical presentations of formal

and informal networks are compared to reveal the interplay of formal and informal networks. According to the result of correlational analysis and the implications of SNA metrics explicated, the impact of the interplay of formal and informal networks on the project performance could be probed.

The density of a network measures the extent to which actors are extensively interacting with each other. The smaller the network density in a PBO-based network, the better the project performance shall be. Smaller *DoF* of the network density in a PBO is equivalent to better fit of formal and informal networks in terms of density, which is confirmed to have a positive impact on project performance. This supports the hypothesis that higher density of formal or informal networks does not necessarily lead to better project performance; it also depends on the level of fit between the two.

Both average path length and diameter reflect the level of interaction convenience for actors within networks. They share a similar implication in organizational research in that a smaller value leads to more convenient interactions. The main difference is that average path length measures the average reachability, while the diameter describes the maximum distance of all node pairs. The smaller *DoF* of the average path length (or diameter) in a PBO is equivalent to the better fit of formal and informal networks in terms of path length (or diameter), which is confirmed to have a positive impact on project performance.

Degree centrality, closeness centrality, and betweenness centrality are the three measures of centrality at the individual level in SNA, which relates to individual members' influence and power within a PBO. These measures indicate that an individual with higher centrality has a more important role in the organization. Smaller *DoF* of either centrality measure in a PBO is equivalent to the better fit of formal and informal networks in terms of centrality, particularly in the consideration of average effects. However, the hypothesis for the Betweenness centrality is rejected with a non-significant correlation coefficient. Betweenness centrality is a reflection of the mediating effects in controlling and transmitting information flows within the network.

In the vocabulary of organizational studies, the four concepts are closely related to organizational cohesion (relevant SNA metrics including but not limited to density, average path length, degree centrality, and global clustering coefficient), organizational efficiency (relevant SNA metrics including average path length, diameter, and closeness centrality), and organizational effectiveness (relevant SNA metrics including degree centrality, betweenness centrality, and local clustering coefficient). By employing SNA, the formal and informal networks of PBOs were deciphered as a series of vivid graphs and quantitative numbers, and then their interplay is confirmed to perform an important role in the achievement of better project performance.

5. Conclusions, implications and limitations

The above discussions point to the conclusion that the higher extent of 'fit' between formal and informal network could be conducive to a better the project performance of PBOs, under the

condition that the individuals of PBOs have relatively stable and normative working behaviours. The method used in this study provides a new perspective for the management board to probe into the informal working networks, to evaluate the original organizational design and collaboration mechanism, and then to more efficiently steer the operation of the PBOs. In reality, the working behaviours of individuals are also changeable under proper guidance. A good manager shall be able to make instrument for a more collaborative and trust organizational culture through the upper-down structural design of the PBO, and meanwhile be able to get a clear view of the informal networks, e.g. through the bottom-top feedback.

Within the boundaries of PBOs, formal networks set up the organizational skeleton for interaction and information exchange between project members, while the informal networks reflect the actual communication patterns and information flow. A denser informal network is perceived to be more cohesive, as long as the fit between formal and informal networks has reached a certain level. A project manager could diagnose organizational effectiveness by checking the fit of network density between the formal and informal networks. When a low level of fit is discovered, a project manager could take one of two intervention approaches. One is to investigate the formal institutions to see whether the work task-related communications among the corresponding professionals are sufficient, and if not, missing or long-distance information channels may be bridged at the organizational structure level, e.g. by using facilitating technologies. The other approach is to initiate informal institutions (e.g. project team camps).

This study is conducted in an innovative way to integrate SNA approaches, institutional thoughts and project management theories together, and the findings are limited to some factors, which shall be aware and improved in the future research activities. Firstly, the number of the case studies is relatively small, and the generalization of the findings in this study needs more evidence to decode the interplay of formal and informal networks and its impact on the PBO performance. Secondly, the significance level of the statistical analysis is marginal, and hence they are better treated as “indicative” instead of “decisive”. The quantitative analysis should be understood in conjunction with the qualitative analysis. Thirdly, SNA is a promising research method in providing a big toolkit for the organizational study scholars to explore, however, as to the authors’ knowledge, the exploration is just a corner of the iceberg. Particularly, the bridge between graphical / mathematical presentations of SNA and practical implications in organizational study is yet to be shortened.

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Direct Cost of Rework - A Subcontractor's Perspective

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Abstract

While it is widely recognized that additional costs due to poor quality have a significant impact on construction project success, limited research has been conducted to determine the direct cost of quality. When studies were conducted on the direct cost of quality (rework) they were usually from the perspective of the general contractor or owner and not from that of the subcontractor, where quality improvement would be most impactful. This study identifies the previously published work on the direct cost of rework; their data sources, perspectives, and calculations in an attempt to compare and contrast these investigations and add new data generated as a part of this research. An analysis of the inspection failure rates of subcontractors on California hospital projects was conducted and through a targeted survey the subcontractor's average cost of rework was identified in order to develop an additional cost analysis approach when calculating the true direct cost of rework. Previous research identified that the direct cost of rework typically ranged from 2.1% to 6.6% of the total project contract value with a mean of 4.2%. Utilizing a direct cost of rework calculation from a subcontractor's perspective, a cost percentage of 0.55% was calculated based on the total subcontractor contract value. These results delineated a clear and significant difference in the direct cost of poor quality depending on one's project perspective. This paper contributes to the study of quality by recognizing the true cost of rework from a subcontractor's perspective which assists industry in better understanding the motivations to improve quality. By recognizing the true cost of rework, steps can be taken to identify and reduce rework cost and ultimately further enhance construction project cost performance.

Keywords: Quality, Hospital Construction, Inspections, Direct Cost of Rework, Subcontractor

1. Introduction

The three criteria for assessing the success of a construction project are known as the 'iron triangle' of time, cost, and quality (Atkinson 1999). The first two objectives are relatively straightforward to define and measure: a subcontractor is either ahead or behind schedule, either over or under budget. Quality, the third objective, is much more difficult to assess and has received only limited attention in academic literature (Morris and Hough 1997). Quality control (QC) is the consensus term for a construction inspection process that verifies the quality of construction projects after work has been completed. This is in line with Crosby (1980) who defines quality succinctly as the conformance to established requirements.

This measurable description of quality is the foundation on which third-party quality control inspections are based for general contractors and more importantly for subcontractors whose perspective this study purports. Failed third-party inspections and the resulting direct cost of rework (also termed deviations), have been one cause of unnecessary construction costs attributed to lack of quality or cost of quality (COQ). If construction quality fails to meet the established criteria (applicable codes and contract document requirements) then additional resources must be spent (or wasted) on quality costs to make corrections. One goal of the construction process is to decrease the number of failed inspections (quality failures) and thus decrease the direct cost of rework or the direct cost of poor quality (DCOPQ). Being able to accurately and consistently calculate the DCOPQ across varying project types is an important factor in finding solutions.

While the cause of rework is an important topic and one which has garnered some attention, purporting and calculating the cost of rework has been widely inconsistent. A study was conducted on the quality inspection results from six California hospital construction projects. A survey was employed in an effort to uniquely calculate the Field Rework Cost (FRC) from the perspective of subcontractors. Based on this investigation a new calculation for the DCOPQ or direct cost of rework was developed and discussed to better understand and consider the entire concept of construction rework cost.

2. Background

2.1 Construction Rework Cost

For the purposes of this research, rework is seen as a negative term best defined by Rogge et al. (2001) as an activity in the field that has to be done more than once or activities that remove work previously installed as part of the project. A study conducted by Love and Edwards (2004) summarized most of the prior research conducted on the cost of construction rework. Their study emphasized the small amount of work done on the subject to date and the large disparity in the results. It was hypothesized that these variations were a result of researchers using different scope assessments, data collection methods, inconsistent calculations, and varying definitions of the term quality. A continuation of Love and Edward research can be

found in Table 1 which is partially inclusive of their work and additional research found since their 2004 publication.

Table 1: Summary of reported total direct cost of construction rework studies.

Author	Descriptor	Cost %	Formula	Data Source	Perspective	Country	Project Type
Hwang (2009)	Field Rework Factor	2.12%	Total Direct Cost of Rework / Construction Cost	Project Reports	Owners and General Contractor	Various	Various Types
Love (1999)	Direct Rework Cost	2.40%	Rework Var. + Non-Var. + Defects / Contract Value	Single Case Study	Owner and General Contractor	Australia	Industrial
Burati (1992)	Deviation Cost	2.50%	Construction Deviation Cost / Total Project Cost	Nine Case Studies	CI Data Collection	USA	Industrial
Simpeh (2012)	Direct Rework Cost	2.93%	Direct Cost of Rework / Original Contract Sum	Survey	Construction Professionals	South Africa	Various Types
Ledbetter (1994)	Rework Cost	3.10%	Rework Cost Design + Construction / Project Cost	Single Case Study	General Contractor	USA	Heavy Industrial
Love (1999)	Direct Rework Cost	3.15%	Rework Var. + Non-Var. + Defects / Contract Value	Single Case Study	Owner and General Contractor	Australia	Residential
Willis (1996)	Quality Deviations	3.30%	Deviation Correction Cost / Project Value	Single Case Study	General Contractor	USA	Chemical Plant
Barber (2000)	Quality Failure	3.60%	Quality Failure Cost / Contract Value	Single Case Study	General Contractor	UK	Highway Project
Mills (2009)	Defect Cost	4.10%	Defect Cost / Contract Value	Owners Claims	Owner - Housing Guarantee Fund	Australia	Residential
Josephson (2002)	Direct Rework Cost	4.40%	None Conformance Cost / Total Project Cost	Seven Case Studies	Owner and General Contractor	Sweden	Various Types
Josephson (1999)	Defects	4.85%	Defect Cost / Production Cost	Seven Case Studies	Owner and General Contractor	Sweden	Commercial
Love (2010)	Direct Rework Cost	5.07%	Direct Cost of Rework / Original Contract Value	Survey	Various Contractors and CM Co.	Australia	Heavy Civil
Hammarlund (1994)	Quality Failure	6.00%	Quality Failure Cost / Contract Value	Single Case Study	General Contractor	Sweden	Commercial
Love (2002)	Direct Rework Cost	6.40%	Direct Cost of Rework / Total Project Cost	Survey	Senior Construction Prof.	Australia	Various Types
Love & Edwards (2005)	Direct Rework Cost	6.40%	Mean Direct Cost of Rework %	Survey	Design, Contractors, & Consult	Australia	Various Types
Barber (2000)	Quality Failure	6.60%	Quality Failure Cost / Contract Value	Single Case Study	General Contractor	UK	Highway Project

This updated summary of reported rework cost studies reinforces the continued wide variation of descriptors, calculation formulas, data sources, and project types which researchers have utilized. These disparities and their lack of cohesion only adds to the confusion when rework cost comparisons are made between studies. As Love and Edwards (2004) reported and the results of Table 1 support, “while the calculation of rework can be an arduous and time-consuming task, there is an imperative need for rework definition and measurement before an accurate assessment of direct costs can be made” (p. 208).

Regardless of the descriptors used or how the calculation were formulated, all the research generated to this point indicate a version of the total direct cost of rework divided by the total

project value or contract value. Undoubtedly construction research would benefit greatly from these values being calculated identically, so they can be directly compared industry-wide regardless of specific project circumstances. Unfortunately, the driving force when identifying the cost of rework and the formulas used have often been dictated by the data available. When this existing data is summarized a mean cost of 4.2% is calculated based on some determination of total cost of rework versus some total contract value.

2.2 Subcontractor Perspective

On commercial construction projects general contractors have typically subcontracted to specialty subcontractors as much as 75% to 100% of the work (Schaufelberger and Holm 2002). Despite the fact that subcontractors complete a large portion of most construction project, issues concerning subcontracts are seldom acknowledged or discussed. As Arditi and Chotibongs (2005) confirmed, “little research has been conducted and little information is published on this topic” (p866). Efficient subcontracting (increased inspection success and reduced rework) would benefit all parties involved in the construction process including the general contractor, the owner, and the subcontractor.

Most research conducted in the areas of quality, quality control, and cost of quality has been from the perspective of the general contractor or the owner (Barlow 2015). A focused literature review on this topic as summarized in Table 1 confirms the lack of attention to subcontractor rework cost. Methods that improve the chances of subcontractor success by ensuring that all aspects vital to a subcontractor go well should be put in place (Boynton and Zmud 1984). This paper focused on the true cost of rework from a subcontractor’s perspective where the final quality of a construction project is truly determined. Unlike previous calculations of rework, the formula supported by this study is the direct cost of rework from a subcontractor’s perspective:

$$\frac{\text{Subcontractor's Total Direct Cost to Correct Inspection Failures}}{\text{Total Subcontract Contract Amount}} = \text{Field Rework Cost (FRC)}$$

In order to decrease quality inspection failures, which is the direct cause of rework, one must start with the subcontractor. The subcontractor carries the primary responsibility of obtaining quality success on a project, all others exist to support their efforts. Only by understanding and measuring subcontractor inspection success can we hope to decrease the amount of rework, decrease the DCOQ, and thus decrease the total cost of rework on any construction project.

2.3 California Hospital Construction

In California, healthcare construction projects are subject to a separate design review and construction inspection process due to their specialized nature and importance to the public. The California Office of State-wide Health Planning and Development (COSHPD) performs the regulatory oversight. In particular, the Facilities Development Division (FDD) of COSHPD reviews and inspects all healthcare construction projects in California. The FDD conducts plan reviews; issues building permits; confirms seismic compliance; performs construction observations and inspections; and interprets regulations, building codes, and policies.

In 2014, the FDD had over \$20 billion worth of healthcare projects either under plan review or in construction (OSHPD 2015). In addition, the amount of anticipated healthcare construction to occur in California during the next ten years is predicted to be over \$100 billion dollars. Alfeld (1988) advanced the view that construction, due to its magnitude alone, promises a greater payback for performance improvement than almost any other industry. Any small step in the direction of reducing the COQ due to inspection failures and rework in this field will likely save millions of dollars. The resources wasted on failed construction inspections could otherwise be spent on more desirable aspects of the healthcare cost ledger, such as lowering consumer costs for healthcare or saving lives.

3. Research Methodology

3.1 Mining Existing Data

This study first mined existing third-party construction quality inspection data generated by the FDD on six major California hospital projects. The data quantitatively revealed COSHPD inspection successes and failures at a subcontractor level over the entire project. The existing data were extracted and downloaded into MS Excel spreadsheets for further sorting and analysis. The data were gathered remotely and after-the-fact, eliminating any form of bias and avoiding what is known as the Hawthorn effect (Franke and Kaul 1978), referring to the tendency of individuals to perform differently when their performance is being measured or observed.

All six hospital projects were constructed in California under the review and supervision of COSHPD. All projects were completed between 2009 and 2014, varied in total construction cost between \$260 million and \$550 million, and varied in total area between 28,000 and 60,000 square meters validated continuity of the data. No further information about the projects is provided in this study to keep the identity of the projects, the owners, the architects/engineers, general contractors, and subcontractors confidential. COSHPD generated data had several advantages over other possible sources of quantitative inspection data generated by architects, engineers, general contractors, and privately hired consultants. All healthcare construction projects were required to accommodate continuous on-site inspections by the FDD, thus normalizing the inspection data. The FDD's policies and procedures for inspections, data gathering, and record keeping were standardized across all hospital projects, required by law, and conducted over the entire construction process.

COSHDPD quality control inspection data were obtained and analyzed from forty-one (41) different subcontractors spanning six different California hospital projects. The breakdown of the forty-one subcontractors by trade, number in each trade, and designated reference number is shown in Figure 1. In order for a particular subcontractor who worked on one of the six hospital projects to be chosen for this research, a minimum of 150 inspections conducted by a COSHDPD inspector was required. This minimum number was used to distinguish between subcontractors who had a significant role in the project and those who were ancillary.

Framing & Drywall (7 each); FD1, FD2, FD3, FD4, FD5, FD6, FD7*

Electrical (6 each); EL1, EL2, EL3, EL4, EL5, EL6

Structural Concrete (5 each); SC1, SC2, SC3, SC4, SC5

Wet Mechanical (5 each); WM1, WM2, WM3, WM4, WM5

Fire Sprinklers (5 each); FP1, FP2, FP3, FP4, FP5

Dry Mechanical (4 each); DM1, DM2, DM3, DM4

Ceiling Panels (3 each); CP1, CP2, CP3

Insulation (2 each); IN1, IN2

Fire Stopping (2 each); FS1, FS2

Exterior Framing (1 each); EF1

Glass & Glazing (1 each); GG1

* FD7 exists because one of the six hospital projects used two framing and drywall subcontractors due to the size of the contract.

Figure 1: Subcontractors by trade, number, and designation.

Table 2 below shows a breakdown of the forty-one subcontractors, the hospital projects on which they worked, and the number of inspections that they conducted. Inspection success was later converted into percentages to normalize the comparison between subcontractors who had varying numbers of inspections.

Table 2: Subcontractors by project, designation, and number of inspections.

Hospital 1		Hospital 3		Hospital 5	
1. FD1	1536	20. FD4	3390	33. FD6	2622
2. FD2	771	21. EL3	3320	34. EL5	378
3. EL1	1023	22. SC3	343	35. SC4	772
4. SC1	571	23. FP3	519	36. WM4	1988
5. WM1	1002	24. DM3	1049	37. FP5	197
6. FP1	269	25. CP3	241	Subtotal	5957
7. DM1	835	26. IN2	1152	Hospital 6	
8. CP1	262	Subtotal	10014	38. FD7	4252
9. IN1	190	Hospital 4		39. EL6	2138
Subtotal	6462	27. FD5	4904	40. SC5	1745
Hospital 2		28. EL4	1819	41. WM5	1802
10. FD3	3775	29. WM3	1658	Subtotal	9937
11. EL2	5196	30. FP4	265	TOTAL	
12. SC2	462	31. DM4	525	61,070	
13. WM2	2406	32. FS2	1886		
14. FP2	429	Subtotal	11057		
15. DM2	2011				
16. CP2	452				
17. GG1	340				
18. FS1	1503				
19. EF1	1069				
Subtotal	17643				

3.2 Subcontractor Survey

Data reliability is related to data source and is therefore inextricably linked to the position held by the person who completed the questionnaire (Oppenheim, 1992). An individual survey was sent specifically to the subcontractor's field project manager in-charge of the project and from which the above existing mined inspection data was obtained. The survey was returned fully completed by thirty-nine of the original forty-one subcontractors; two subcontractors were not available or unwilling to participate. The survey focused on the actual cost of a failed third-party quality control inspection. The survey questions were as follows:

- SQ1 – What was your total subcontract amount?
- SQ2 – How many man hours were required to correct an inspection failure?
- SQ3 – How much in material costs were required to correct an inspection failure?
- SQ4 – How much equipment cost were required to correct an inspection failure?
- SQ5 – How many man hours were required for the re-inspection process?

Figure 2: Subcontractor Survey Questions

4. Results

4.1 Data Mining Results – Total Inspections

A total of 61,070 COSHPD inspections data points were analyzed from six hospital construction projects spanning forty-one subcontractors. Major subcontractors on a significant California hospital project could generally expect that nearly 1,500 inspections might be required of them

on any particular hospital project. This piece of data may not particularly useful, knowing that the average number of inspections required for any particular subcontractor will vary greatly. Subcontractors of a particular trade, however, could benefit from the results shown in Figure 3, which identifies the average number of inspections broken down by subcontractor trade. Figure 3 brings into focus the wide variation in the number of inspections possible depending on the subcontractor trade. The values listed represent the number of subcontractors representing a particular trade, the mean number of inspections, the minimum, and the maximum number of inspections respectively.

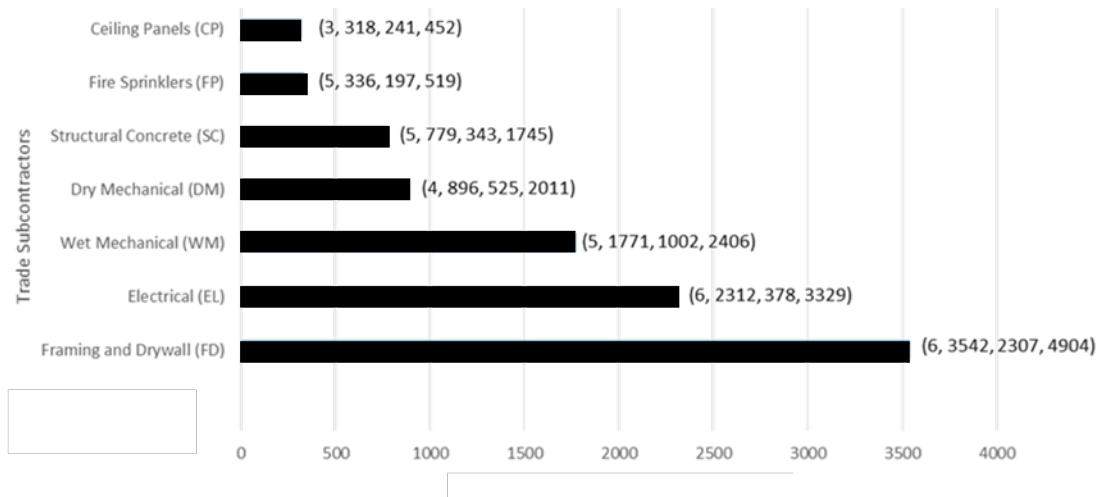


Figure 3: By trade and (number of subcontractor's, mean, minimum, and maximum number of inspections).

4.2 Data Mining Results – Failed Inspections

The percentage of COSHPD re-inspections (or failed inspections) versus total inspections revealed that 9.07% of all inspections conducted resulted in a failed inspection. The range of results was a minimum percentage (best subcontractor performance) of 2.02% and a maximum percentage (worst subcontractor performance) of 21.82%. As a result of a failed inspection, the work inspected was redone (re-work), a re-inspection was requested, and a new inspection was conducted by COSHPD. The overall re-inspection percentage number is based on over 60,000 inspection attempts with a standard deviation of 5.55%.

Subcontractors were then ranked based on percentage of failed inspections, ranking high achieving (low percentage of re-inspections) to low achieving (high percentage of re-inspections) as shown in Table 3. A re-inspection rate range of 2.02% to 21.82% was observed, as was a fairly even distribution of trade types along the spectrum. This would indicate that re-inspection rates had no particular correlation to the type of subcontractor trade being inspected.

Table 3: Ranking of subcontractors by percentage of re-inspections.

<u>Subcontractor</u>	<u>Re-inspection</u>			
	<u>Rate %</u>			
1. FD7	2.02%			
2. WM5	2.16%	22. WM1	7.98%	
3. EL6	2.18%	23. EL2	8.33%	
4. SC5	2.34%	24. DM3	9.06%	
5. FD2	2.98%	25. DM1	9.58%	
6. WM3	3.20%	26. FS2	9.86%	
7. SC2	3.46%	27. FD4	9.88%	
8. FD3	3.81%	28. IN2	10.07%	
9. DM4	3.81%	29. FP2	10.96%	
10. FD1	4.48%	30. FP3	11.95%	
11. SC1	4.55%	31. IN1	12.11%	
12. SC3	4.66%	32. FS1	12.38%	
13. EL5	5.29%	33. CP2	13.05%	
14. FD5	5.93%	34. GG1	13.82%	
15. CP1	6.11%	35. CP3	14.94%	
16. FP5	7.11%	36. EL4	15.28%	
17. FP4	7.17%	37. WM4	17.71%	
18. EL1	7.23%	38. FP1	19.33%	
19. EF1	7.30%	39. WM2	20.28%	
20. DM2	7.86%	40. SC4	21.76%	
21. EL3	7.98%	41. FD6	21.82%	

4.3 Survey Results

To determine the subcontractor’s direct cost to correct each failed inspection (rework), questions SQ1-SQ5 (see Figure 2) were asked as part of a survey. The responses were analyzed and the mean amounts are shown below (Figure 4) based on an N=39.

SQ1 Total Subcontract Amount	\$28,468,384 (US\$)
SQ2 Man Hours to Correct	6.3 Man Hours
SQ3 How Much Material Cost	\$238 (US\$)
SQ4 How Much Equipment Cost	\$96 (US\$)
SQ4 Man hours to Re-inspect	3.8 Man Hours

Figure 4: Mean results from subcontractor survey.

Direct Cost of Quality (DCOQ) per failed inspection was calculated (see Figure 5) for this sample (N=39) subcontractors. The cost per man-hour rate, including workers’ compensation insurance and overhead, was estimated at \$80.00/hour (based on the 2015 RS Means Carpenter/Foreman/ Superintendent blended rate for California, USA).

Labor Cost Correct (6.3MH x \$80/hr)	= \$ 504
Material Cost Correct	= \$ 238
Equipment Cost Correct	= \$ 96
Labor Cost Re-inspect (3.8MH x \$80/hr)	= \$ 304
Subcontractor’s Average Cost per Inspection Failure	= \$1,142

Figure 5: Failed inspection calculation.

From the mining of inspection data results discussed earlier, it is estimated that significant subcontractors on California hospital projects averaged approximately 1500 inspections per project at a 9.07% inspection failure rate. Based on these numbers, a subcontractor could typically expect to incur $(1500 \times 9.07\% \times \$1,142) = \$155,369$ of direct re-work expense (DCOQ) from a subcontractor's perspective. At an average subcontract amount of \$28.5 million per project, the percentage of DCOQ for a substantial subcontractor working on a California hospital project is approximately $(\$155,369 / \$28,500,000) = 0.55\%$ Field Rework Cost (FRC). This percentage is lower than that found in other studies which calculated the DCOQ based on the entire construction project.

5. Discussion and Conclusions

Previous studies on the topic of construction quality have primarily focused on the cause of quality failures, the cost of quality due to rework, and identifying the reasons for project success. These studies are all from a primary stakeholder's perspective, most notably the general contractor. Interestingly, there were no studies found that examined the issue of quality from a subcontractor's perspective in an attempt to document inspection failures, improve inspection success, and decrease the DCOQ. This study assessed the construction quality of California hospital projects from the perspective of subcontractors in the field and through COSHPD third-party quality inspection data. The old adage, "you can't manage what you don't measure" (Deming 1986), is a rudimentary goal of this study. This research aimed to create measurements and benchmarks where none existed to assist subcontractors and project teams to better manage the quality inspection process on construction sites.

This study found that the DCOQ from a subcontractor's perspective was only 0.55%, far below the project wide calculations. While there is a wide variation when comparing these results, they may both be correct, because the total DCOQ for the total project with general contractor costs, mark-ups, etc. included may justify the higher percentage range as compared to the just subcontractors direct cost of rework. The motivation to decrease the additional cost of rework on large construction projects from a general contractor's and owner's point-of-view are clearly understandable at 3% to 6% of total project cost, especially when the significant indirect costs associated with poor quality are also considered. At 0.55%, and with very little additional indirect costs, what is the motivation for the subcontractors to decrease their amount of rework and DCOQ? Subcontractors may be very comfortable with a percentage such as this. General contractors and owners might find it difficult to motivate subcontractors to decrease this percentage further when it is such a small amount to begin with.

Gathering, analyzing, calculating, and benchmarking quality inspection data at a subcontractor level was unique to this study. For the first time, using our approach, subcontractors and the rest of the construction project team can utilize measureable quality inspection data to gauge the relative success of the quality obtained in the field. This new approach when applied early on in the construction process can alert project teams when a quality issue exists and action by management is required to rectify either the quality management process, quality assurance

program, and/or the quality control program responsible for the relatively poor inspection results.

By applying this study, subcontractors could more accurately calculate the direct cost of rework due to failed quality inspections to determine the actual DCOQ for their particular trade and company. Depending on the results, a subcontractor can determine if taking corrective action for quality assurance is necessary or if the rework percentage is acceptable and simply a cost of doing business. General contractors and owners might choose to further motivate subcontractors financially to decrease rework and the DCOQ with various incentive programs if subcontractors are unwilling to take additional quality assurance action on their own. Future studies should look at the reason for these failed inspections and why they were not corrected prior to a formal inspection process. Indirect costs resulting from inspection failures such as lost productivity, acceleration costs, and work flow disruption is an issue which should also be further explored.

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A Study on the Factors of Completion Time for Road Construction Projects

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Abstract

Studies indicate that there is a relationship between project cost and construction time for different construction types. The purpose of this study is to validate the time-cost relationship model developed by Bromilow et al. in context with road construction projects in Florida. The model was extended to include contract types to determine whether the variable also has an effect on project duration. Data related to 235 road construction projects was obtained for the study. SPSS[®] program was used for analysis of the data. The statistical technique used for the analysis was stepwise linear regression. The results indicate that both actual construction cost and contract type have a statistically significant relationship with construction time for road construction projects in Florida, at the level of significance (p-value) of <0.0001 . A prediction model of construction time was developed based on the results of the study. This model will be useful to both graduate and undergraduate students taking courses related to cost estimating and construction project scheduling, and also to professionals involved with the construction industry.

Keywords: Construction Time, Construction Cost, Contract Type, Road Construction, Regression Analysis

1. Introduction

1.1 General

Construction time for any type of project is related to a wide range of variables including construction cost. Time and cost have been typically used as important criteria for determining project performance globally. A relationship exists between the time taken for construction of a project and the cost incurred to complete it. Project cost has been identified as a correlate of construction time in many regions of the world (Bromilow et al., 1980; Choudhury & Rajan, 2008). In the construction industry, contractors usually use previous experiences to estimate the project duration and cost of a new project. In general, the more time it takes to complete an activity, the more human resources have to be engaged for the task, resulting in a higher project cost.

A correlation between completed construction cost and the time taken to complete a construction project was first mathematically ascertained by Bromilow et al. (1980). The authors analyzed the time-cost data for a total of 419 building projects in Australia to develop the model. The equation defining the mean construction time as a function of project cost was found to be:

$$T = K * C^B \quad (1)$$

Where

T = duration of construction period from the date of possession of site to substantial completion, in working days

C = completed cost of project in millions of dollars, adjusted to constant labor and material prices

K = a constant indicating the general level of time performance per million dollar

B = a constant describing how the time performance is affected by the size of the construction project measured by its cost.

The model indicates that the duration of project time of a construction project is basically a function of its total cost. It provided a basis for all parties concerned with the construction procedure to establish a fairly accurate probable duration of a project in days, given the estimated cost of the project. The authors also analyzed the overruns on cost and time that provided a measure on the accuracy of the industry's time and cost prediction.

The model also indicates that relationship between duration of a construction project and time required to complete it is non-linear. A hypothetical scenario of such relationship, developed by the author, is shown in Figure 1. In order to perform data analysis using a linear model, the variables need to be transformed into their natural logarithms.

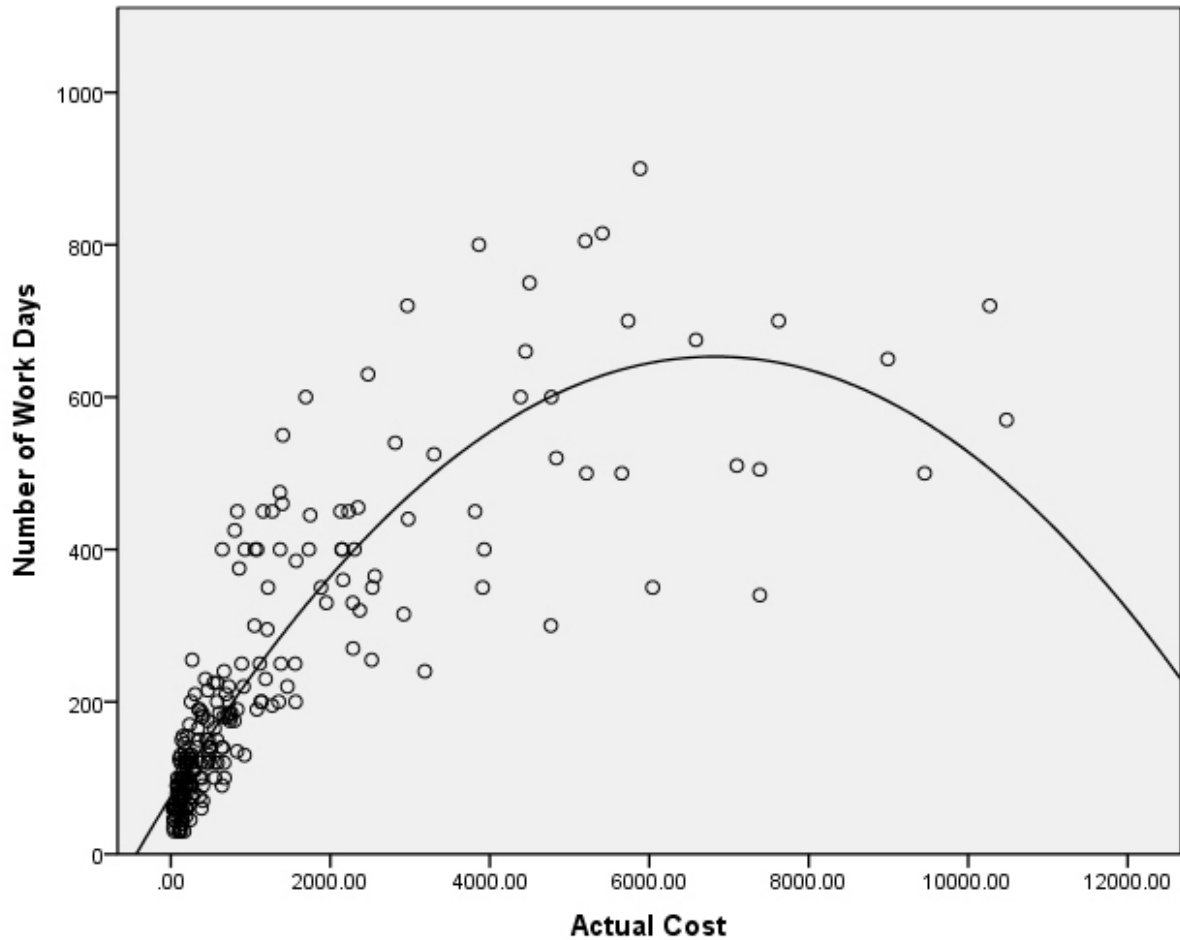


Figure 1: Non-linear relationship between construction cost and time

Several other studies have been performed around the world to make similar predictions for either a specific sector of construction or construction industries, in general. Ireland (1985) replicated the study to predict construction time for high-rise buildings in Australia; Kaka & Price (1991) conducted a similar survey both for buildings and road works in the United Kingdom; Chan (1999) investigated the effect of construction cost on time with particular reference to Hong Kong; and Choudhury & Rajan (2008) conducted a study on residential construction projects in Texas. Hoffman et al. (2007) used Bromilow et al.'s (1980) time-cost model to analyze data collected for 856 facility projects. They, however, included certain other variables such as project location, building type, and delivery method in the model.

Gritzka & Labi (2008) conducted a study on factors of time delay, specifically for road construction projects. Findings of their study indicate a statistically significant relationship between longer-duration projects and cost overrun.

All these studies found that the mathematical model developed by Bromilow et al. (1980) is applicable for prediction of construction time when the cost of construction is known.

1.2 Other Possible Factors of Road Construction

A critical issue in road construction that affect project delivery, experienced almost worldwide, is cost overrun (Bhargava et al., 2010). It generally results from factors that occur during various stages of life-cycle of a project. Studies on highway projects have been conducted by quite a few researchers to seek the extent of this particular problem.

Findings by several authors indicate that it is associated with project design, project environment, and project size (Akinici & Fisher, 1998; Hinze et al., 1992); project size, of course, is directly related to overall construction time.

Construction procurement is the process of obtaining services and supplies for efficient and timely delivery of the end product. The major project delivery methods include (1) Design-Bid-Build, (2) Design-Build, and (3) Construction Management at Risk. Studies indicate that project performance is affected by project delivery method (Choudhury & Pitkar, 2007; Ling et al., 2004; Chan et al., 2002).

The trend in the use of project delivery system is changing rapidly. Project delivery system has evolved over the years. The medieval master builder was hired by an owner to design, engineer, and construct an entire facility. This system was common until the early 20th century. With changing technologies, it was necessary to change the type of delivery system that gave way to the Design-Bid-Build method. As the specialization of services increased, it was found that the interaction during design phase was extremely poor which resulted in inefficient designs, increased errors and disputes, higher costs, and ultimately longer schedule. This led to the Construction Management at Risk delivery system to improve the interaction among parties concerned and to overlap the design and the construction phases. Eventually, it was found necessary for owners to resort to a single source Design-Build contracting (El-Wardani et al., 2006). There is an increasing trend toward the use of the Design-Build delivery method in the public sector (Choudhury & Pitkar, 2007; Tulacz, 2006; Yakowenko, 2004).

It is thus possible that project delivery method could play a role in construction performance time. The likelihood of an impact of delivery method on construction time of road projects was ascertained by including it in the time-cost relationship model.

1.3 Hypotheses

From a review of literature, it is hypothesized that

1. (H1) The mathematical model developed by Bromilow et al. (1980) holds good for prediction of construction time for road projects.
2. (H2) The actual completion time of road construction projects in Florida is affected by actual construction cost.
3. (H3) The actual completion time of road construction projects in Florida is affected by estimated construction cost.
4. (H4) The actual completion time of road construction projects in India is affected by contract type or delivery method.

2. Methodology

2.1 Data Collection

Data for 235 completed road construction projects undertaken by Florida Department of Transportation (FDOT) was obtained from secondary sources. All construction works were completed within last five years.

2.2 Variables

Actual Construction Time (TIME): It is the actual time measured for the completion of a road construction project. It was measured in days. This variable was labeled as LNTIME after being transformed into its natural logarithm.

Actual Project Cost (ACOST): It is the total cost of construction works of a road construction project. It was measured in units of 1000 US Dollars. This variable was labeled as LNACOST after being transformed into its natural logarithm.

Estimated Project Cost (ECOST): It is the total cost of construction works of a road construction project, estimated by FDOT prior to construction. It was measured in units of 1000 US Dollars. This variable was labeled as LNECOST after being transformed into its natural logarithm.

Contract Type (CONT): It is the type of contracting used for delivering a road construction project. This was a dummy variable consisting of two categories: (1) Design-Build (DB), and (2) Others. This variable was labeled as LNCONT after being transformed into its natural logarithm. It was assigned a value of 1, if the contracting method was DB; if not, a value of 0 was assigned.

3. Results

3.1 Analysis

The time-cost relationship model developed by Bromilow et al. (1980) defines only the relationship between construction time and actual construction cost. Since the present study hypothesizes relationships to exist also between (1) construction time and estimated construction cost and (2) construction time and contract type, the model had to be modified. Following model encompasses both the variables that may have an effect on construction time performance:

$$\text{TIME} = K * \text{ACOST}^{\beta_1} * \text{ECOST}^{\beta_2} * \text{CONT}^{\beta_3} \quad (2)$$

A stepwise linear regression analysis was used to perform the first step of analysis (see eqn. 3). It is a semi-automated process of building a model by successively adding or removing variables based on the *t*-statistics of their estimated coefficients. Therefore, the variables had to be transformed into their natural logarithms.

$$\text{LNTIME} = \text{LNK} + \beta_1 \text{LNACOST} + \beta_2 \text{LNECOST} + \beta_3 \text{LNCONT} + \varepsilon \quad (3)$$

Where LNK = natural logarithm of K; $\beta_1, \beta_2, \beta_3$ = regression coefficients; and ε = error term.

The results show that two independent variables were retained by the model: actual construction cost (LNACOST) and contract type (LNCONT). Estimated contract cost (LNECOST), not being statistically significant at the level of 0.5, was excluded. The results are shown in Table 1.

Table 1: Stepwise Linear Regression Analysis for LNTIME

<i>Variable Retained</i>	<i>Intercept (LNK)</i>	<i>Regression Coefficient</i>	<i>t</i>	<i>p< t </i>	<i>Critical Value of t </i>
<i>Intercept</i>	1.827		15.976	<0.0001	1.96
<i>LNACOST</i>		0.529	29.976	<0.0001	
<i>LNCONT</i>		-0.131	-2.234	0.026	
<i>F-value of the Model = 459.471</i>	<i>p>Model F=<0.0001</i>	<i>Model R² = 0.89</i> <i>Adjusted model R² = 0.80</i>			

3.2 Interpretations

The *F*-value of the model used for multiple regression analysis was found to be statistically significant at less than the 0.0001 level. This provides evidence that a relationship exists between construction time and at least one of the independent variables used in the model. The results indicate that construction cost ($p>0.0001$) and contract type ($p>0.026$) are correlated to construction time. The other variable, estimated construction cost, was not found to be significant at level of significance of 0.05; hence, it was automatically excluded by the statistical program from the model.

An important aspect of a statistical procedure that derives model from empirical data is to indicate how well the model predicts results. A widely used measure the predictive efficacy of a model is its coefficient of determination, or R^2 value. If there is a perfect relation between the dependent and independent variables, R^2 is 1. In case of no relationship between the dependent and independent variables, R^2 is 0. Predictive efficacy of this particular model was found to be moderately high with an R^2 of 0.89, and an adjusted R^2 of 0.80. It means that at least 80 percent of the variances in construction time of projects are explained by actual construction cost and contract type.

Based on the findings, research hypothesis (H1) regarding application of Bromilow et al.'s (1980) model for prediction of construction time for road projects could not be rejected; *F*-value of the model was statistically significant. Research hypotheses (H2) and (H3) related to relationships between actual completion time and cost of road construction projects (Figure 2) and actual completion time and contract types for road construction projects in Florida could not also be rejected; relationships of both these variables with actual construction time were statistically significant. However, hypothesis (H4) indicating a relationship between actual completion time and estimated construction cost for road projects in Florida had to be rejected, because relationship of this variable with construction cost was not found to be statistically significant at the 0.05 level.

The relationship between time and cost was found to be statistically significant at the level of less than 0.0001. The relationship between time and contract type was found to be inverse at the level of less than 0.026. It means that construction duration was less using design-build type of contract.

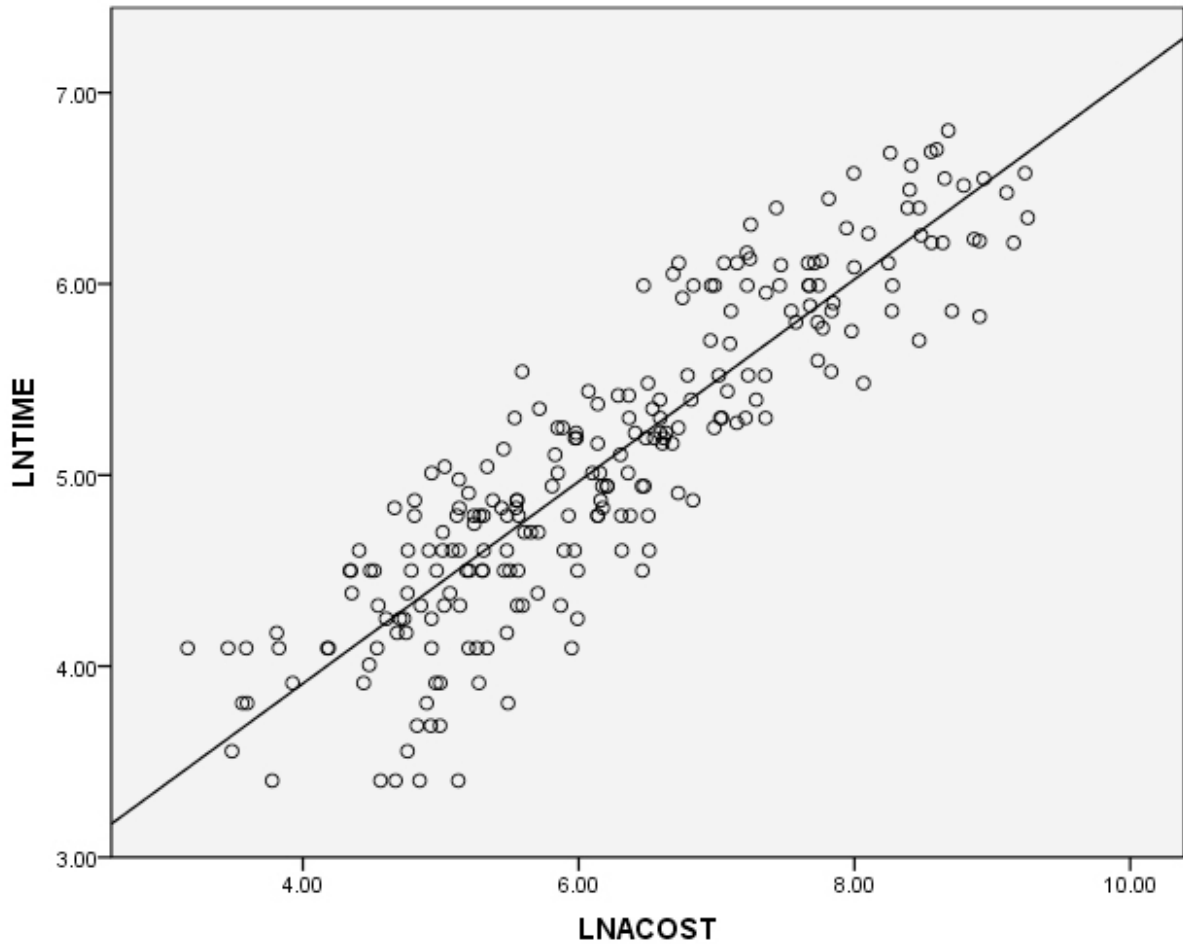


Figure 2: Relationship between LNTIME and LNCOST

The prediction model for road construction time in Florida was developed using results of the analysis. Bromilow et al.'s (1980) model was modified by adding contract type to the equation. The value of LNK and LNCONT were required to be transformed to K, using an exponential function [$\exp(\text{LNK})$] and [$\exp(\text{LNCONT})$] respectively, for expressing the model in its original form (Equation 4). The model may be expressed as follows:

$$\text{TIME} = 6.215 \cdot \text{ACOST}^{0.529} \cdot \text{CONT}^{-1.31} \quad (4)$$

This model can be used to predict the road construction time in Florida when the gross floor area is known. For example, if the actual construction cost of a road project is, say \$5,000,000, the predicted construction time for the project would be about 494 days.

4. Conclusions

The results of the study provide evidence that a modified version of the mathematical model developed by Bromilow et al. (1980) is applicable for prediction of time for road construction projects in Florida. Apart from cost, contract type was also included in the model.

The results of the statistical analysis indicate that for a road construction project in Florida, an increase in construction cost results in an increase in total construction time. The results also indicate that contract type has a statistically significant effect on actual construction time of the projects. It takes less time for completion of a road project in Florida using design-build method of delivery.

The model will be useful for students of construction science, taking courses in construction project scheduling. It will also be useful for all parties associated with the construction industry to predict the mean time required for the delivery of a road project. It provides an alternative and logical method for estimating construction time, both by bidders and clients, to supplement the prevailing practice of estimation predominantly on individual experience.

This study has been conducted using data for construction of road projects in Florida. The construction industry can benefit from the results of the study by applying the model in predicting construction time for similar projects. Such models may be developed by collecting historical data either from the owners or the constructors. However, the model documented in this study applies only for road construction projects in Florida and cannot be generalized beyond the sample size.

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Lean Sustainable Indices: A case for South African Public Infrastructure Sector

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Abstract

The interwoven nature of the goal of lean and sustainability points to synergy that can be created for industry, and societal benefits. The paucity of studies, which dwell on the impact of lean and sustainability on construction project performance is however notable. This is the case of public sector infrastructure projects (PSIP), which form the focus of this research. This exploratory study assesses the indices required for measuring the integrative implementation of lean and sustainability concepts in an infrastructure project. The study is qualitative in nature, based on interpretative theoretical framework that is grounded in lived experiences of project stakeholders. Emergent findings indicate that although the generic internal project key performance indices (KPI) of cost, time and quality is of major concerns to the stakeholders, indices required for integrative implementation of lean and sustainability are more broader in satisfying various stakeholders concerns, which would match business and environmental excellence, energy efficiency and optimum indoor environment, minimized resource consumption, minimized emissions, increase health and well-being, user productivity, reduced noise and dust pollution, stakeholders collaboration, and community social benefits. Such benefits include employment and enhanced industry competitiveness. It can be argued that a focus on these indices could lead to project delivery with limited impact in terms of sustainable development.

Key words: Construction, Lean, Infrastructure, Sustainability, South Africa

1. Introduction

The last decades witness a lot of innovation and transformation in its expedition for an improved built environment. Infrastructure development is crucial to drive the economy and advance civilization (Mirza, 2006). Achieving a sound and well-functioning infrastructure is essential for continuous economic growth, international competitiveness, public health and overall quality of life, as demanded by the current generation within the available social and natural context. However, this interrelationship between social and natural boundaries could alter the ecosystem. Environmental symptoms such as worsening climate change and huge emission of greenhouse gases (GHG), as a result of the depletion of natural resources because of the need to consumption is a global reality. As a result, sustainability has emerged in construction lexicon (Abidin and Pasquire, 2007).

The World Commission on Environment and Development (WCED, 1987) propounded the definition of sustainable development. The definition, which has been widely adopted by multiple agencies, says that sustainable development is meeting the basic needs of the present and the right for a better life without compromising the ability of future generations. The import of this definition is placed on the balance between social development, economic development, and environmental sustainability (Shen et al., 2007). Based on this, the primary goal of infrastructure development has now expanded from been mere economic viability to social and environmental concerns. Major infrastructure procurement now involves expert considerations regarding major spheres of sustainability. The triple bottom line (TBL) of economic, social and environmental dimensions qualifies for legislative, financial, and professional backings necessary for procurement success (Opoku and Ahmed, 2015). Infrastructure sustainability has grown from being technical based perspectives into social-political dimensions, attracting the attentions of multi-disciplinary experts, nations, and pressure groups in an attempt to negotiate the best way for sustainable development. This has been furthered by the recent adoption sustainable development goals (SDGs) by the United Nations (UN). The goals are premise on the need to build safe and resilient infrastructure, and combats climate change. The goals also include sustainable use of resources, promotion of inclusive and sustainable industrialization, which foster innovation.

This new concept focuses on the impacts of infrastructure development and resource use. The focus is on how efficient management can be brought to bear on energy consumption, dust and gas emission, noise pollution, waste generation, water discharge, water use, land use and pollution, and consumption of non-renewable natural resources, and its effect on the needs of current and future generations (Ghosh et al., 2014). Various researchers have shown that the construction industry and its activities have significant effects on the environment (Ding and Lanston, 2004; Griffith, et al., 2005; Low *et al.* 2009). Several work (Kibert, 1994; Hill and Bowen, 1997; Madu and Kuei, 2012) have proposed the thinking that underpins sustainability for the construction industry in order to engender wastes minimization and prevention of environmental hazards through basic principles of 5Rs (rethink, reduce, reuse, recycle and report) to achieves long-time economic and social benefits. Sustainability goals can only be achieved if construction activities are informed and directed by new thinking, new resources and

expertise. Some of this comes in the form of innovative practice, tools and enhanced process models, but much will have to come from situated and contextual appreciations of sustainability goals and local practices in the industry (Pathirage et al., 2007).

Similarly, lean as a concept was developed as an industry process of eliminating waste by adapting production process in construction to enhanced performance (Howell, 1999; Forbes and Ahmed, 2011). Rybkowski et al. (2013) look at lean construction as respecting stakeholders in the value chain through a holistic pursuance of continuous improvement, while minimizing waste and maximizing value to the customer. Howell (1999) sees lean construction as a production process that mainly redresses project KPIs balance by ‘increasing value while reducing waste’ in construction. This production process is often anchored on waste reduction and normally practiced in the segregation of construction process breakdown of project life-cycle. Most works on lean construction have been premised on the five principles of lean thinking that serve as a pathway for continuous improvement. These principles are: value, value stream mapping (VSM), flow, pull, and perfection (Pasquire and Connolly, 2002; Terry and Smith, 2011). These principles are used to mitigate the current practices in infrastructure procurement that often hinders the attainment of the criteria for sustainability (Vieira and Cachadinha, 2011).

The interwoven nature of the goal of lean and sustainability points to a synergy that can be created for industry, and societal benefits. Construction industry can leverage on the synergy between lean and sustainability to achieve infrastructure development. Lean concepts align with sustainability concept of doing more with less. What is not clear though and is worthy of further investigation is; how can lean and sustainability indices be used to promote stakeholder engagements in the built environment? The paucity of studies which dwell on the impact of lean and sustainability on construction project performance is notable (Novak, 2012; Campos *et al.*, 2012). This is the case of public sector infrastructure projects (PSIP), which form the focus of this research. Monitoring progress towards lean and sustainability (LS) practices, thus, requires the identification of operational indicators that provide manageable units of information on economic, environmental, and social conditions that can be measured. A full disclosure of this new paradigm and the ability to fully map out its performance indices will be beneficial to the industry, and enhanced the process of continuous improvement and attainment of ecosystem equilibrium for sustainable development. The proposed will assist developers and others stakeholders gain a more comprehensive view of the lean and sustainability in the construction context.

2. Sustainability in Construction

Over the last three decades, sustainability concept has been growing in significance in the areas of developments in the built and natural environments (Edum-Fotwe and Price, 2009). After probing for answers to the challenge of sustainable development, most nations refocus their attentions on the construction industry. The construction industry is important to the achievement of the sustainable development agenda. The South African government has made progress in establishing policies that favour energy savings in the built environment. Appreciation of the major impacts of construction activities on sustainable development has led to the development of various management approaches and methods to guide construction

participants in achieving better project sustainability performance in South Africa (Du Plessis, 2007; Thomson and El-Haram, 2011).

Kibert propose 7 principles to implement sustainable construction practice in 1994. These principles cover most aspects of the TBL and the concept of “doing no further harm” to the built environment. These construction principles speak to: conserving, to minimise resource consumption; reuse, to maximise reusable resources; renewing/recycling, to optimise renewable or recyclable resources; protecting, to conserve the natural environment; eliminate toxic materials, to create a healthy and non-toxic environment; economic benefits, to apply life cycle cost analysis; and technical, to provide quality products. Adopting these principles will ensure the reduction / elimination of adverse effects of construction activities on the built environment through efficient use of resources. The outcomes of sustainability principles could be regarded as a vital ingredient of improved competitiveness in construction industry (Opoku and Ahmed, 2015). Sustainable construction fosters interaction and protection of natural and social environments and ultimately helps to reduce energy usage, enhanced healthy and improved condition of living, and promote stakeholders productivity.

3. Lean in Construction

Stakeholders’ concern about inefficiency in the construction industry is well known. The monumental wastes accompanying the use of resources (energy, water, materials, and land) have contributed immensely to climate change. Business as usual can no longer be sustained in the construction industry, if the industry is to assure biophysical sustainability while maintaining competitiveness (Womack and Jones, 2003; Holton et al., 2010). Lean offers an alternative that allows construction activities to thrive within environmental and social-economic constrains. Based on lean principles, major sources of waste, inefficiencies and pollution within the construction processes are identified and eliminated through collaborative approaches and processes to create value. For instance, planning, measurement, adjustment, and improvement (“Plan, Do, Check, Act”) have also prove to be a veritable framework for value creation beyond specification (Ng et al., 2012).

Various lean principles and tools have been developed for use in construction with varying degree of success. San Martin and Formoso (1998) state that lean performance indicators include value chain efficiency, process efficiency, production flexibility, improved skills, material diversity, standardization, and optimization of components weight. Generally, the collaborative and continuous improvement principles inherent in lean practices made it not only a wastes reduction philosophy, but catalysts for business competitiveness, productivity and profitability. Lean principles engender effectiveness and efficiency in production processes by systematically examining the value chain for non-value activities through critical thinking and planning improved projects performance (Corfe, 2012; Novak, 2012).

4. Lean and Sustainability in Construction

The emergence of sustainability issues calls for a more innovative approach for the world to survive within the present constrains. The construction process generally contributes to the total energy use, GHG emission, and waste generation. Utilizing lean tools bring forth the predicted

variable of efficiency and waste reduction, and the responsive variable of environmental benefit through reducing construction wastes at source, minimizing resource depletion, and preventing pollution. Integrative deployment of lean and sustainability could increase the pace of broader enhanced value (Larson and Greenwood, 2004; Ghosh et al., 2014).

Despite the sustainable construction drivers reported in the literature - resource efficiency, competitive advantage, reputation, increased productivity, reduced wastage, reduced materials cost, and preservation of natural environment (Yates, 2003; Zhou and Lowe, 2003) , the uptake of sustainability is still limited in the industry. This limitation may not be unconnected with the complex and fragmented nature of the construction industry. Common challenges perpetrating the limitation are the lack of understanding, perceived costs, and inadequate expertise (Opoku and Ahmed, 2015). However, lean reputation for promoting collaborative working arrangements, coordination, waste and cost reduction, and continuous learning and improvement serves as an opportunity for the industry to mitigate barriers to sustainable construction and create value beyond specifications.

The opportunity for value beyond the specifications has emerged as construction process with highly developed lean practices have reliably broken through the traditional project constraints and serve as catalyst for sustainability and enhanced added value in meeting the needs of sustainability (Nahmens and Ikuma, 2009; Novak, 2012). Lean practice covers a wide range of infrastructure procurement practices: planning and risk management, collaborative working, problem definition and solving, and value stream efficiency. These lean approaches demonstrate the value stream (benefits in terms of cost, time, and sustainability) for infrastructure sustainable development that span the project life cycle. It is on this premise that governments are urging the industry to leverage on lean thinking for real value delivery whilst simultaneously achieving improved competitiveness and the objectives set out in the strategy for sustainable construction (HM, 2009 cited in Corfe, 2013). It follows that lean thinking could form a central part of organisations' sustainability strategies, as it could deliver sustainability objectives.

Lean sustainable construction therefore can be conceptualized as 'a proactive approach to project delivery practice that meets a broader sustainability concerns of environmental, economic, social and technical perspectives by leveraging on available effective and efficient concepts to attain sustained productivity'. Sustained productivity here means to exceed the status quo of project delivery practice and achieve infrastructure beyond specifications. This has been achieved through efforts to enhance infrastructure project performance, reduce resource use and reduce costs through lean tools such as BIM, just-in-time, 5R, 5W (Scanlon and Davis, 2011; Ahuja et al., 2014).

5. Research Methodology

The aim of this study is to develop holistic indices of integrative implementation of lean and sustainability in terms of infrastructure development. The indices could allow a better understanding of stakeholders' way of assessing public infrastructure project performance. Within the construction context, the understanding of KPIs serves as benchmark for improved productivity, and it is vital to the success of project goals. To resolve this challenge, an exploratory study was conducted in Bloemfontein, South Africa. The study relies on interpretative theoretical framework that is grounded in lived experiences of project

stakeholders (Creswell, 2013). Purposeful sampling in which the participants are selected according to a defining characteristic that makes them a role player was utilised in the study (Nieuwenhuis, 2007; Leady and Ormrod, 2010).

In particular, nine stakeholders in infrastructure development were interviewed in six different entities (department of works, project managers, consultants, policy administrator, community representative and the academia) with semi-structured questions that were initially sent to them by e-mail and a follow up telephone call was used to confirm the actual date of the interview for consistency. The interviews were conducted over a period of two weeks. Interviews, generally, were between 20 to 30 minutes in duration. At the start of the interviews, each participant was reminded of the research question and of the interview process. Each interviewee was then provided with a covering letter to read, and a confidentiality agreement to sign; on demand. This process was then followed by the actual interview during which the interview protocol was utilized as a guide. Each interviewee was asked about his / her experience and perceptions of infrastructure performance indicators related to: economic, environmental, and social conditions. All interviews were recorded and transcribed. The emerging findings were then collaborated with a comprehensive literature review to explore the phenomenon in South Africa. Nine interviewees took part in the exploratory study. The interviewees were two women and seven men between the ages of 30 and 56. The educational levels of the participants ranged from a national diploma to a doctoral degree, and construction industry experience ranged from 3 to 32 years (Table 1).

Table 1: The demographic of interviewee

<i>S/N</i>	<i>Descriptions</i>	<i>Highest Level of Education</i>	<i>Entities</i>	<i>Designations</i>	<i>Years in Industry</i>
1		<i>Bachelor's Degree</i>	<i>Works department</i>	<i>Project supervisor</i>	3
2		<i>Master's Degree</i>	<i>Consultant</i>	<i>Project manager</i>	24
3		<i>National Diploma</i>	<i>Project managers</i>	<i>Site agent</i>	11
4		<i>Bachelor's Degree</i>	<i>Consultant</i>	<i>Architect</i>	26
5		<i>Honours Degree</i>	<i>Project managers</i>	<i>Managing director</i>	25
6		<i>Doctoral Degree</i>	<i>academia</i>	<i>Senior Lecturer</i>	19
7		<i>Honours Diploma</i>	<i>Works department</i>	<i>Junior manager</i>	11
8		<i>Honours Degree</i>	<i>Community rep.</i>	<i>User</i>	8
9		<i>Honours Degree</i>	<i>Policy administrator</i>	<i>Director</i>	32

6. Research Findings and Discussions

The findings are herein presented and discussed in line with natural and social concerns about biophysical, economic, technical and social dimensions of sustainability in order to cater for the concern of different stakeholder. This provides a platform to integrate the primary data and the literature for meaningful interpretation for the right indices to emerge.

7.1 Indices for Biophysical Dimension

Most environmental concerns appears to be the highly researched sustainability dimension, some of the issues of the environment are predicated on the interaction between natural and social issues. Most interviewees suggest that resource use is a global issue as concerns for global warming are not localised. Sustainable resource use and environmental impact assessment are considerations in any developmental agenda, where the goal is to achieve sustainable extraction of fossil fuels and minerals resources at a rate lesser or equal to the slow replenishment of the inert resources, and to reduce the use of 4 generic resources of energy, water, materials, and land.

An attempt to maximise resource reuse and / or recycling, use renewable resources in preference to non-renewable resources, minimise air, land and water pollution, minimized emissions. So as to maintain and restore the earth's vitality and ecological diversity; and minimise damage to sensitive landscape in order to achieve the expected continuum (Shen, et al., 2007). Interviewees were unanimous in saying "we all know the rate at which we depletes the natural resources is certainly not sustainable, and a stable weather condition is not only good for our health, it also good for future planning". This echoes the current unpredictable nature of the biosphere and it impact on the environment. The interviewees express preference for facility with efficient energy, good indoor environment, and limited noise and dust pollution that can aid productivity.

7.2 Indices for Economic Dimension

Cost and value for money are the main determinants between internal and external stakeholders in any potential infrastructure development of scale. The management of the inherent trade-offs between these parties determine the viability of the project. Most interviewees agree with Shen et al. (2007) that intending user's affordability, employment creation; enhanced competitiveness, environmentally responsible supply chains, and the capacity to meet the needs of future generations are the main fulcrum for economic sustainability. Interviewee 5 says "yes, we all want to put up an energy efficient building or green building as you call it, but those technology are beyond the reach of common man", while interviewee 8 says "any user will like to rent a sustainable built environment because it ultimately reduces energy and maintenance costs of the properties". These quotes demonstrate the significance of energy use to the economics of the stakeholders. Other economic aspects mentioned by the interviewees relate to: having a competitive edge over their industry rivals through organizational learning, innovative ideas, technological advancement; improved productivity for enhanced profits; and stakeholder's collaboration for sustained harmony that engendered business and environmental excellence.

7.3 Indices for Social Dimension

The social dimension of sustainability has been growing in importance as a criterion for evaluating the viability of projects in the construction sector, especially in developing nations where basic needs of life and the right skills for quality job remains a challenge. Social sustainability in construction is mostly premises on the need for improve quality of human life through implementation of skills acquisition and capacity enhancement of the disadvantaged, to seek fair or equitable distribution of construction social costs, and to seek intergenerational equity (Shen, et al., 2007; Edum-Fotwe and Price, 2009). This social cost, according to the interviewees pertains to the health and well-being of the community. Most interviewees agree that “a lean sustainable project should be able to contribute to the community through local employment and improved skills development”. A segment of the interviewees also echoes the need to match business goals with environmental excellence. This can only be attained through stakeholder collaboration and community involvement/development, proper site layout to reduce noise and dust pollution for work place harmony.

7.4 Indices for Technical Dimension

Quality is one of the traditional KPIs in construction management. Although relative in nature, it depends on technical competence and its outputs express ‘value for money’. Sustainability in technical terms is to construct durable, reliable, and functional structures, which creates the built environment; humanize large buildings; and revitalize the existing urban infrastructure (Shen et al., 2007). Most interviewees agree with Emuze (2015) that the new model of sustainability must include regenerative, adaptive and resilient initiatives in order to achieve a broader sustainability agenda. The quality of the design, material selection, production process and the level of finishes most at times determine the functionality and the price clients are willing to pay for the products. Also, poor quality of work in projects may lead to reworks which certainly compromise other performance indices.

7.5 Indices for Lean and Sustainable Projects

The traditional KPIs have evolved overtime from the dated tripod of cost, time and quality. Projects success are now evaluated through performance measures to include critical factors of; health and safety and related sustainability criteria (Khosravis and Afshari, 2011; Kylili, Fokaides and Jimene, 2016). The broader sustainability indices have been widely reported (Shen et al., 2007; Edum-Fotwe and Price, 2009; Emuze, 2015) to encompass the natural and socio-economic aspects of infrastructure development and its effect on various stakeholders in the industry.

These cut across the project value chain in relation to processes, resources, leadership, people, financial, environmental and the entire ecosystem through project lifecycle. Lean principles as a waste reduction tool, is an effective way of enhancing the various spheres of KPIs for infrastructure development (see sections 3 and 4). It can then be inferred that indices for lean and sustainability (LSI) are those indices that can be seen as a standard of judgement by which lean and sustainable values can be measured. Hence, the LSI went beyond traditional indices to accommodate external inclusiveness that address industrial harmony and the need of future

generations. As illustrated in Table 2, these indices set a benchmark for measuring project performance holistically and provide significant insights into developing a comprehensive base for future developments.

Table 2: Stakeholders project performance indices

<i>Types</i> <i>Indices</i>	<i>Traditional</i>	<i>Lean (L)</i>	<i>Sustainability (S)</i>	<i>LSI</i>
<i>Cost</i>	✓	✓	✓	✓
<i>Time</i>	✓	✓	✓	✓
<i>Quality</i>	✓	✓	✓	✓
<i>Health and Safety</i>	✓	✓	✓	✓
<i>Environmental responsible value chain</i>		✓	✓	✓
<i>Energy and resource consumption</i>		✓	✓	✓
<i>Pollution and emission</i>		✓	✓	✓
<i>Matching Business and environment</i>		✓	✓	✓
<i>Social cost/benefit</i>			✓	
<i>Industry competitiveness</i>		✓	✓	✓
<i>5R / Renewable resources</i>		✓	✓	✓
<i>Flexibility and adaptability</i>		✓	✓	✓
<i>Organizational learning</i>		✓	✓	✓
<i>Dispute</i>	✓	✓	✓	✓
<i>Stakeholders collaboration</i>		✓	✓	✓
<i>Employment and Skill development</i>		✓	✓	✓
<i>Continuous improvement</i>		✓	✓	✓
<i>Planning and risk</i>	✓	✓	✓	✓

<i>management</i>				
<i>Value stream efficiency</i>		✓		
<i>Technological advancement</i>		✓	✓	✓
<i>Affordability</i>		✓	✓	✓
<i>Indoor environmental quality</i>			✓	

Adopting these new sets of performance measures as a base for planning and executing future projects could lead to evolution of sustainable built environment. To do so, a clear understanding of the LSIs, as a sub-set of biophysical, economic, socio and technical dimensions will be needed. This can come to fruition through further research and stakeholders’ engagement in term of standardizing LSI measurement methods (Ali, Al-Sulaihi and Al-Gahtani, 2013).

7. Conclusions and Recommendations

The purpose of the research reported upon in this paper is to develop lean sustainability indices that are grounded in stakeholder’s projects experience with the view of creating a consistent and holistic way of assessing public infrastructure project performance. The compilation of the indices is relevant as projects performance criteria are often hedged around the traditional KPIs and TBL of sustainability, measured both objectively and subjectively, in order to achieve success expectations. To sum up, the emergent findings indicate that although generic project KPIs of cost, time and quality is of major concern to the stakeholders, indices requires for lean and sustainability are however, broader and far reaching in engendering efficiency and effectiveness in infrastructure development. These include matching business and environmental excellence, energy efficiency and good indoor environment, minimized resource consumption, minimized emissions, increase health and well-being, user productivity, reduced noise and dust pollution, stakeholders’ collaboration, community social benefits, and enhanced industry competitiveness. It can therefore be argued that a focus on these indices could benefit project delivery with limited whole life cycle impact in terms of sustainable development. The indices could provide all stakeholders the same information and knowledge of the overall goals, creating cooperation, coordination and better understanding of the key issues affecting the value chain, towards achieving better project performance.

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Status quo and future development of lean construction in Hong Kong

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Abstract

The current construction industry in Hong Kong faces severe challenges in relation to increasingly stringent regulations, aging workforce and skills shortages and their triggered high labour costs, and the transition of development from the fast-speed to sustainability-oriented mode. Lean construction has been recognised as an effective approach to improving productivity, hence offering a potential for the Hong Kong construction industry to prosper in the challenging circumstance. The aim of this paper is to examine the current practices and explore the future development of lean construction in Hong Kong. The research was conducted through 30 semi-structured interviews with established professionals in the industry. The results indicate a low level of awareness of the lean concept although some lean construction techniques were already embedded in practices implicitly. A wide range of benefits were identified, which were centred on reduced input, increased output and reduced impact, offering a potential for productivity improvement. However, challenges were also revealed at individual, organisational and industry levels, markedly people's mind-set and reluctance to change, a lack of demonstration of the benefits, and a weak knowledge base of lean. While some regarded lean as today's solution and therefore a must-to-have, others speculated an uncertain and dynamic future of lean construction in Hong Kong. Recommendations were identified for promoting lean construction in Hong Kong, fundamental to which was collaboration engaging government, industry and institutions.

Keywords: lean construction, productivity, industry development, Hong Kong

1. Introduction

The construction industry has long been criticised in many countries and regions for low levels of performance in relation to cost and time overruns, poor quality, disputes, and other problems leading to impaired efficiency and waste. It has also been argued as one of the weakest sectors in innovation, with piecemeal adaptation of modern technologies (Woudhuysen and Abley 2004). Much of the research in construction has attributed the lag-behind performance to the nature of the industry that is highly fragmented in structure and complex in operation, and has reached a consensus on the urgent need for reform and innovation in the industry (Dubois and Gadde 2002; Woudhuysen and Abley 2004; Goodier and Pan 2010).

Productivity is an essential component of industry performance which can be illustrated by a ratio between output and input (Park et al. 2005). The need for improving productivity is a great concern in the construction industry. In Hong Kong, the seminal Henry Report ‘Construct for Excellence’ (Construction Industry Reviews Committee – CIRC 2001) proposed ‘an integrated construction industry that is capable of continuous improvement towards excellence in a market-driven environment’. More recently, the Hong Kong’s Construction Industry Vision 2020 (Hong Kong Construction Association – HKCA 2012) has set the target of improving by 50% productivity by 2020 against 2012 benchmarks. However, in parallel with the ambitious goals, there are pressing challenges facing the Hong Kong construction industry to meeting these targets. One of the most significant issues is the ever increasing demand for manpower, accompanied with skills mismatch and the ageing labour force (Wong et al. 2015; Ng and Alan 2015). The great shortage of skilled labour poses significant risks to the fulfilment of a productive industry. In addition, safety is a thorny problem that the accident rate of the construction industry ranked the top among all sectors in Hong Kong (Wong et al. 2015). The impact of construction on the environment is also critical in Hong Kong, in terms of the large amount of carbon emissions and wastage demolition (Hong Kong Green Building Council – HKGBC 2014). To tackle these challenges and thrive in the dynamic circumstance, the adoption of modern technologies and innovative ideas is of great importance in the Hong Kong construction industry.

Lean construction has been widely recognised as an effective approach to improving productivity in the construction industry, e.g. in the UK (Egan 1998; Wolstenholme 2009), US (Salem et al. 2006; Song and Liang 2011), and Canada (Mao and Zhang 2008). Koskela et al. (2002) defined it as “a way to design production systems to minimize waste of materials, time, and effort in order to generate the maximum possible amount of value”. Lean Construction Institute (2015) described it as “a new way to design and build capital facilities whilst the reliable release of work between specialists in design, supply and assembly assures value is delivered to the customer and waste is reduced”. The many definitions and descriptions of the concept of lean construction in literature, albeit varying from each other, indicate the underlying common purpose of value maximization and waste minimization in construction projects. Along with the development of lean construction globally there have emerged numerous lean construction techniques and tools, with a trend attempting to address the emerging concepts and practices in the construction industry, such as building information modelling (BIM),

sustainability, advance planning, and visualisation. For examples, Salem et al. (2006) studied six lean construction techniques: last planner, increased visualisation, first-run studies, huddle meetings, the five S's and fail-safe for quality. Song and Liang (2011) developed a vertically-integrated scheduling system tool for implementing lean thinking to improve project cost and time performance as well as reducing environmental impact of construction. Sadreddini (2012) described in detail two lean construction tools, i.e. collaborative planning and visual management, and considered them to be the first two commonly used to ensure quick wins and start a roll-out of lean and culture change. All these studies emphasise the importance of selecting and applying appropriate tools in a given situation.

However, the take-up of the lean approach in the Hong Kong construction industry appears to be low, coupled with few lean construction tools and technologies in use. Understanding of lean construction may reside with individuals in the industry and academic domains (e.g. Li et al. 2012), while such body of knowledge is fragmented and insufficient. Leung and Tam (2008) identified that the term "lean construction" is not commonly applied by practitioners in the Hong Kong construction industry. These factors not only expose the Hong Kong construction industry to risks and uncertainties when facing the rapidly evolving technologies and innovations, but hamper further take-up and future development of lean construction for achieving the construction industry vision and productivity improvement target.

The aim of this paper is thus to examine the current practices and explore the future development of lean construction in the Hong Kong construction industry. Following this introduction and methodology, the paper examines the perspectives of lean, the status quo of lean construction in Hong Kong, and achieved and potential benefits of and challenges for lean construction. It then explores the future development of lean construction in Hong Kong and identifies relevant recommendations, before conclusions of the paper are drawn.

2. Research Methodology

This research aimed to examine the lean thinking and applications in the Hong Kong construction industry. Semi-structured personal interviews were carried with established professionals in the industry. The interviewees were selected using the cluster sampling strategy, and covered the key stakeholder groups of lean construction in Hong Kong, e.g. developer/client, contractor, specialist contractor, architect, engineer, manufacturer and supplier, government, institution. Previous research (Warren 2002) argued that interview-based research should target between 20 and 30 interviewees for academic publication purpose. Therefore, this study targeted 30 interviews, achieved from 43 invited professionals with a response rate of 70%. Each interview took around 45 minutes, guided by a number of questions in three aspects: the status quo of lean construction in Hong Kong; benefits of and challenges for lean construction in Hong Kong; and future development of lean construction in Hong Kong.

The interviews were audio recorded with permission. The transcripts and notes taken during the interviews were analysed following the process of identifying codes, themes and patterns with the aid of NVivo software.

3. Results and Analysis

The background information of the 30 interviewees is provided in Figure 3. The interviewees together, by their primary affiliated organisations, covered all of the eight main stakeholder groups in the Hong Kong construction industry identified for this study, which were institution (30%), contractor (17%), consulting engineer (17%), developer/client (13%), government department (10%), manufacturer and supplier (7%), specialist contractor (3%) and architect (3%). The interviewees together also well covered various groups of stakeholders by their working experience. Nearly half of the interviewees (46%) had more than 30 years of experience in the construction industry, followed by those with 10-19 years of experience (20%) and then those with 20-29 years of experience and those with less than 10 years of experience.

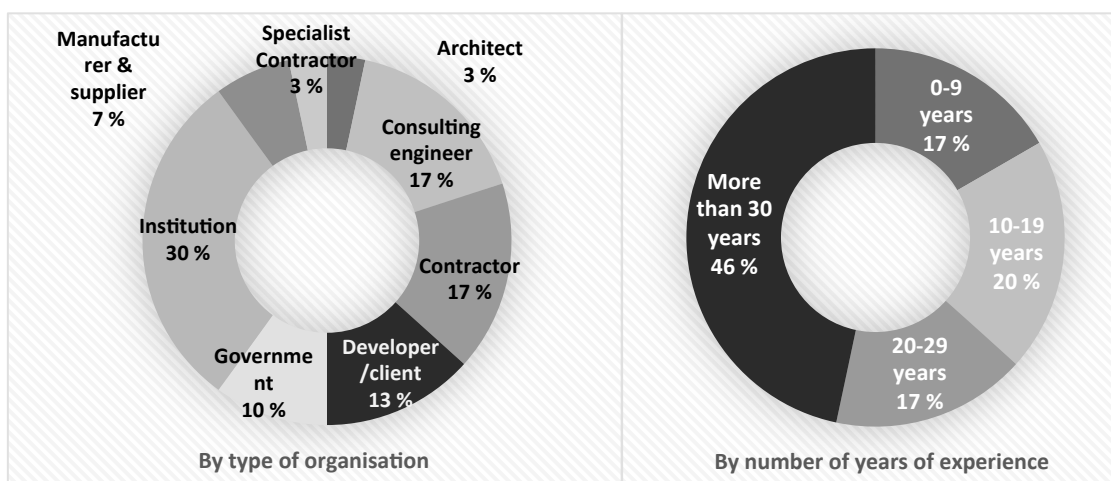


Figure 1 - The demographic information of the interviewees

3.1 Status quo of lean construction in Hong Kong

3.1.1 Understanding of the term “lean construction”

The term “lean construction” was still considered new and uncharted in Hong Kong. More than half of the interviewees (53%) were not familiar with the term. Some of those who knew about the term had not actively adopted the lean construction approach in their practices. Removing those interviewees from institutions (including universities) and consulting engineers (who were assumed to have devoted more efforts in knowledge exploration and exploitation and might have had more exposure to lean), only 12% (2 out of 16) were familiar with the term. It is worth noting that those stakeholder groups who are ignorant of lean are the main actors in the industry. These results suggest that the Hong Kong construction industry is not familiar with the term “lean construction”. The identified perspectives of the concept of lean are summarised below.

Lean construction is from lean production

Over one third interviewees (11/30) commented that lean has its origin in manufacturing such as Toyota automobile production. Applying lean thinking in construction was recognised as a result of cross-industry benchmarking. Hong Kong heavily relies on imported goods while most

construction-related manufacturing facilities have been relocated to Mainland China. Therefore, manufacturing-based innovation like lean may not diffuse well in the construction industry. Thus, the limited awareness of lean explains the poor understanding of lean in construction.

Lean construction is to reduce waste in construction projects

It has been widely reported that applying lean in construction is conducive to the reduction of multifaceted waste in construction projects, including time waste, on-site construction waste, labour waste and other forms of wastages. This was a consensus among the interviewees. Some highlighted only certain kinds of waste, while others had a more comprehensive perspective covering all potential non-value-adding matters within the projects. Besides, it was also brought forward that the construction industry faces different wastage issues from manufacturing and has more on-site wastes. Therefore, although the concept of lean construction was recognized to have originated from lean production, the actual implementation of lean in construction operations is different.

Lean construction is to minimise resources in construction projects

As pointed out by some interviewees, an essential feature of lean is to finish the project with fewer resources in terms of budget, schedule, material, labour, land and other required assets. This perspective is in line with the fundamental lean idea that “lean is to maximise the value”, but emphasizes only the value of the industry itself not the final customers. In Hong Kong’s construction market, the supply, especially housing, has largely failed to keep pace with the demand, which results in a less attention from the industry on the value of end customers, compared to manufacturing or construction market in other competitive places, like Mainland China. These results suggest a missing link in connecting the interests of industry stakeholders and end users in the Hong Kong construction industry.

Lean construction is an integrated approach of life-cycle process management

Lean construction was also viewed as a pillar of project management, with a focus on the integration of processes. Most interviewees considered lean based on the beneficial targets, e.g. reduced waste and minimized resources. Therefore, this perspective offers a slightly different view that concentrates on the pathways to achieve lean. The integration of works at the project level, or more specifically, integrated project delivery (IPD), do put the lean principals into practice. Nevertheless, this perception was only proposed by a few industry experts in the interviews. Indeed, the construction industry is characterised as a competitive and loosely-coupled system (Dubois & Gadde, 2002), while market conditions in Hong Kong are even competitive (HKTDC, 2015). In this respect, the efforts to manage and improve industry performance are more often aimed at individual level rather than enhancing the total project performance, and the power and importance of collaborative integration have often been ignored in the industry.

Lean construction is an overarching theory of project management

Some participants argued that lean construction should be understood as an overarching theory of project management, which covers a range of principles, tools and techniques. They

suggested that the lean concept should be promoted to help achieve a systemic understanding of lean for improving the multiple performance aspects of construction projects. It was argued that the promotion of lean can facilitate the application of lean tools and techniques. Based on these arguments, it was acknowledged that the promotion of the concept of “lean construction” should be important and valuable for the Hong Kong construction industry.

3.1.2 Relevant lean construction practices in Hong Kong

Although the term “lean construction” was not much used in the Hong Kong construction industry, relevant lean practices were identified for improving construction performance.

BIM: a promising but not well-applied technique in Hong Kong

There has been a global transition towards smart and virtual construction, and Hong Kong is of no exception. BIM as the most representative digital technology exerts a tremendous fascination on construction companies. All the interviewees agreed that BIM is an innovative and beneficial practice in the construction field. However, whether it is a lean approach is not clear. Some confirmed that BIM is useful and favourable to achieve lean with the powerful visualization and integration, but others argued that it can be a lean tool only if applied wisely and correctly, e.g.

“There is no button or promise in BIM to tell us when we do something not lean, so to me it’s just a tool and whether it is lean depends on the user. If the user’s mind-set is not lean but mean, I don’t think BIM alone can create lean construction.”

The use of BIM in Hong Kong, although having been highly promoted, was still considered poor. The BIM use has been largely restricted to the design and planning stages. Some interviewee commented,

“Projects labelled with BIM may only exist in names, that they do have BIM consultants come periodically but may have no impact on the real construction works, resulting in a waste of time and resources rather than being lean.”

In this regard, the wide-spread take-up of BIM in Hong Kong would be slow and challengeable.

Low or zero carbon building (L/ZCB): a promotive but uncertain area in Hong Kong

L/ZCB is being promoted in Hong Kong. The first ZCB in Hong Kong has been developed with a collaborative effort across the industry, to showcase the modern energy-saving building technologies and raise the awareness of low carbon living in Hong Kong. However, the possibility of a wide take-up of ZCB in Hong Kong was doubted by some interviewees. One argument was lined in the uncomfortableness a zero carbon environment may offer in such a hot and humid city. Another was concerned with the uncertain feasibility of L/ZCB in the high-rise high-density urban environment of Hong Kong.

L/ZCB was considered not an approach for lean but a scenario for lean application. Whether or not the zero carbon blueprint is a feasible target in Hong Kong, lean techniques were recognized to play a crucial role in reducing carbon footprint and fulfilling building energy saving schemes.

Prefabrication/modular construction: a widely adopted approach in Hong Kong

Prefabrication and modular construction were agreed to be a long-term and well-adopted practice in the Hong Kong construction industry, especially in the public sector. Also, it was seen by almost all the interviewees as an effective lean approach itself and also a useful scenario for embedding lean strategies. Actually, the strength of prefabrication use in Hong Kong was the main supporting argument taken by the interviewees who commented,

“Hong Kong does not use the term “lean construction”, but moves in the same direction to improve construction performance.”

While the use of precast units and modular construction is not new to the industry, there is still room for improvement and being much leaner, as noted by some interviewees. First, better planning is needed involving the usage prediction of precast units, logistics and on-site arrangement. Second, the extent of prefabrication use can be increased. It was reported that around one third of the concrete elements used for public housing in Hong Kong were prefabricated, but the extent for private buildings in the city was much lower. An increased use of prefabrication was therefore suggested. Third, some interviewees suggested that Hong Kong should bring back its precast yards from the Mainland due to the increasing land and labour costs in the Mainland, and time and carbon emissions in transportation.

Look ahead planning tools: an untapped method in Hong Kong

Unlike the other three themes which were widely known, only a few interviewees were well informed with look ahead planning. As look ahead planning is a specific lean approach, this finding is not surprising. It reveals that although interviewees have argued that the Hong Kong construction industry has applied lean practices without labelling the term, a gap still exists in applying some specific lean techniques. An even poorer awareness was identified of Last Planner System, which is one of the most important and far-reaching construction-specific lean techniques that covers look ahead planning as one step. This finding again suggests that advanced lean construction tools and techniques, with the potential to improve construction productivity, are still largely untapped in Hong Kong.

Other techniques undertaken for improving productivity

While employing a formal lean approach is rare in the Hong Kong construction industry, advanced practices to increase efficiency have been adopted in different firms for a long time. During the interviews, industry experts and researchers mentioned a number of other related techniques and methodologies for improving productivity. Examples of such techniques and methodologies include quality control, critical path method, knowledge sharing platform or knowledge transfer system, collaborative delivery methods, data management, design software, reuse of resources, and 5S.

3.2 Benefits of and challenges for lean construction in Hong Kong

A wide range of achieved or potential benefits were identified, which can be grouped under three themes in alignment with the industry-wide concern of improving productivity and competitiveness, namely, reduced input, increased output and reduced impact (Table 1).

Table 1 Identified benefits of lean construction in Hong Kong

<i>Theme</i>	<i>Identified benefit</i>	<i>Example quote</i>
<i>Reduced input</i>	<ul style="list-style-type: none"> • <i>Reduced cost</i> • <i>Saved resources</i> • <i>Reduced project schedule</i> • <i>Saved labour</i> • <i>Saved spaces</i> 	<p><i>'Time and cost are the benefits since lean helps the management to reduce the resources and result in faster projects.'</i> [from institution]</p> <p><i>'If use wisely, it can reduce the number of waste and the number of manpower.'</i> [from developer/client]</p>
<i>Increased output</i>	<ul style="list-style-type: none"> • <i>Higher quality construction</i> • <i>Better customer satisfaction</i> 	<p><i>'We use some machineries and prefabrications, so by using these lean construction tools or techniques or designs, productivity will be enhanced, waste has been reduced, and quality has been improved.'</i> [from institution]</p>
<i>Reduced impact</i>	<ul style="list-style-type: none"> • <i>Reduced construction waste (reduced environmental impact)</i> • <i>Improved safety (reduced accidents)</i> 	<p><i>'Reducing waste in landfill, which I think is a very big issue in Hong Kong'</i> [from consulting engineer]</p>

Six themes of the challenges were identified, grouped at the individual, organizational and industrial levels, leading to the uncertainty and dynamics of its future development (Table 2).

Table 2 Identified challenges for lean construction in Hong Kong

<i>Level</i>	<i>Identified challenge</i>	<i>Example quote</i>
<i>Individual level</i>	<ul style="list-style-type: none"> • <i>People's mind-set</i> • <i>Reluctance to change</i> 	<p><i>'Number one is the concept. People have to have that concept.'</i> [from government]</p>
<i>Organizational level</i>	<ul style="list-style-type: none"> • <i>Lack of demonstration of the identified benefits</i> • <i>Lack of support from the leader</i> • <i>Lack of time to learn</i> 	<p><i>'You need to convince all the big boss to approve of implementing such kind of approaches.'</i> [from supplier]</p>
<i>Industrial level</i>	<ul style="list-style-type: none"> • <i>Lack of knowledge/training in the market</i> • <i>Constraints in the regulatory framework</i> 	<p><i>'Also the policy, I mean the procurement, is not really conducive to innovation.'</i> [from institution]</p>

3.3 Future development of lean construction in Hong Kong

The need for improving construction productivity in Hong Kong was made clear in the interviews, but whether or not to achieve that by promoting lean construction was considered to be uncertain. Some believed that lean is today's solution to tackling the identified challenges, such as labour shortage, environmental concerns and low productivity. Some argued for a dynamic future of lean construction development in Hong Kong, i.e. the future development of lean construction will be associated with uncertainties and diversity. The others considered that the adoption of lean construction may still be stagnant in Hong Kong in the near future. Overall, the future development of lean depends on what challenges exist and how such challenges can be solved, as well as the efforts exerted in the promotion among industry stakeholders.

A number of recommendations were identified from the interviews to addressing the identified challenges and promoting lean construction in Hong Kong. The recommendations are:

- There is an urgent need for more education and training on lean construction.
- Successful cases of utilising lean are highly required to promote and demonstrate the benefits of lean construction.
- Government policies and incentives for adopting lean are impactful.
- Collaboration is critical to utilising lean for improving productivity.
- The establishment of a lean construction organisation in Hong Kong should be useful.

Fundamental to all these recommendations is government-industry-institution collaboration.

4. Discussion

The results from the interviews reveal that lean construction as a philosophy is not well understood in the Hong Kong construction industry as a whole. Although some more established approaches and techniques (some being lean related) have been widely utilised for improving productivity, the adoption of modern lean tools and techniques is limited. The promotion of lean therefore has the potential to broaden the horizon of the industry and facilitate the take-up of innovation, boosting up construction productivity.

The identified benefits of lean construction are primarily of reduced cost, resources and time. These results echo the fundamental principle of lean in waste minimization that unnecessary and repetitive wastage in various forms can be eliminated by applying lean (Womack 1996). Higher quality was also identified, but only by a few interviewees, whereas better customer satisfaction was considered as another benefit by even fewer participants. This result is believed to be presumably due to the severe problem of housing shortage in Hong Kong (Yip 2014), which dilutes the customer focus in the marketing strategy of many construction companies. However, lean is a customer-centric philosophy (Howell 1999). This finding suggests that the little awareness of lean construction in Hong Kong might be attributed to the lack of customer value emphasis in the industry. Along with an increasing global concern on sustainability and low

carbon, the Hong Kong construction industry is now exerting more efforts on waste management and carbon footprint reduction (Pan and Ning 2014). It was also considered that the approach of lean construction can be promoted in Hong Kong under relevant sustainability schemes with its beneficial effects on the reduction of construction waste and resource consumption.

Despite the many identified benefits, challenges for lean are thorny. The results show that a large proportion of construction practitioners in Hong Kong are quite conservative and accustomed to conventional methods of construction. Owing to insufficient labour in Hong Kong (Wong et al. 2015; Ng and Alan 2015), some seldom fear the unemployment crisis and do not see the necessity of applying lean approaches or other innovative methods. It was recommended that more education and training is required to address this ideology. However, as the lean philosophy is really culture and value-laden, education per se may hardly fulfil that purpose. Besides, as the construction industry is fundamentally profit-driven, to fully demonstrate the benefits of lean by using successful project cases will be very important to encouraging construction organisations to take up lean. In this respect, pilot projects demonstrating how lean can help to improve performance are highly recommended. However, due to the lack of knowledge and expertise in the Hong Kong construction industry, pilot cases may be difficult to be developed. Increasing the industry's knowledge base of lean is vital, but the key issue resides with how to build such a knowledge base in this lean-insulated area. Recommendations on government and institutional support and industry-wide collaboration are only effective when industry stakeholders have achieved a comprehensive understanding of lean. Thus, it might be a more effective way to establish a specific lean construction organisation in Hong Kong, which may draw lessons globally, explore lean knowledge attentively, and create a collaborative platform for lean projects formation.

5. Conclusions

This paper has examined the current practices and explored the future development of lean construction in Hong Kong. The paper concludes that lean construction as a philosophy is not familiar to the Hong Kong construction industry at large. Relevant practices, however, have been conducted. BIM and L/ZCB are emerging areas and have received increasing attention in Hong Kong, but still being partial or immature. Prefabrication is a long existing practice and yields great benefits in the Hong Kong construction industry. Look ahead planning tools which are specific for lean construction are still untapped in Hong Kong.

The paper also concludes that wide-ranging benefits of lean construction are available, markedly reduced input, increased output and reduced impact. Examples identified include minimised project input of money, materials, time, labour, land and other kinds of resources, maximised value of the project output in higher quality and customer satisfaction, and reduced impact of construction in terms of less environment related wastage and accidents. Co-existed with the benefits are a number of challenges at the individual, organisational and industry levels. Typical examples of the identified challenges include people's mind-set and reluctance to

change, the lack of demonstration of the benefits, insufficient support from the leaders of construction organisations, and the paucity of knowledge and expertise of lean in the industry.

The paper further concludes that to address the challenges and accelerate the uptake of lean in the Hong Kong construction industry, recommendations are proposed in terms of policy promotion and incentives from the government, knowledge support from institutions and universities, and collaboration across the whole industry. The establishment of a lean construction organisation in Hong Kong should provide an effective way to explore the knowledge and facilitate the future development of lean construction in Hong Kong. Such organisation should aim to disseminate lean related knowledge, develop learning from international practices for the wide industry, provide a collaborative platform for government-industry-academia initiated pilot lean projects, and organise events to support stakeholder communications and engagement.

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Industry Practitioners Quality Perceptions of Built Environment Graduates at Entry Level in the South African Construction Industry

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Abstract

Entry level graduates in the construction industry have been criticised for failing to meet the expectations of the industry. Gaps have been reported between competences possessed and those demanded by industry. These deficiencies impact on the ability of the graduates to acquire employment, maintain the employment, progress in their careers and get a new job when the need arises. Information on the extent of the problem of deficiencies in factors that impact on employability is scanty, if not altogether missing. This research therefore sought to establish the perception of employers in the South African construction industry on the level of preparedness of university graduates entering construction practice. A quantitative survey design approach was used. Data were collected through a structured questionnaire circulated to a purposively selected strata of general contractors registered with the Master Builders Association in the construction industry in South Africa. Descriptive statistics, reliability coefficients and the Kruskal Wallis test were computed and used to identify skills, knowledge, competences and attributes which employers felt were lacking in entry level graduates. The results show that the employers are not satisfied with the quality of graduates from universities in South Africa. Graduates are found to be deficient in knowledge of construction, financial aspects of construction, problem solving, professional practice, oral communications skills, written communication skills, health and safety, self-directed learning, ethics, team working, punctuality, legal and risk aspects of construction, reading and understanding of documents and professional conduct among others. Attributes found to be deficient include negotiation skills, vision, practicality, entrepreneurial attributes, leadership, forward thinking, critical thinking, problem solving, and communication skills among others. On a positive note, graduates were rated fairly well in the desire to learn and information technology skills. The results suggest that employers are very highly expectant of the skills, knowledge, competences and attributes which graduates should bring with them to construction practice from the university. However, while it is important that graduates possess the relevant skills, knowledge, competences and attributes, the employers perception of the relevant extent to which graduates need to demonstrate these at entry level may be overrated.

Keywords: Built Environment Graduates, South African Construction Industry, Graduate Quality, Construction Education, Industry Perception

1. Introduction

The extent to which graduates entering the construction job market are competent for practice has come under question on several occasions. Several deficiencies have been reported including failure to apply practical construction knowledge, absence of problem solving skills, poor communication skills among many other skills critical for the efficient functioning of construction industry practitioners (Aryakwa et al., 2011; Love and Haynes, 2011). Similar deficiencies have been reported in some sections of the South African construction industry (Smallwood and Emuze, 2011).

These deficiencies impact on the ability of the graduates to acquire employment, maintain the employment, progress in their careers and get a new job when the need arises. The ability to achieve these is described as employability. Information on the extent of the problem of deficiencies in factors that impact on employability is scanty if not altogether missing. For example, the British Council (2014) noted the severe lack of information on employability skills that graduates possess and that while employer perspective surveys are usually sources of such information, even these are often absent in some countries. It is consequently difficult to compare employability information across contexts and through time (Ibid). For Sub-Saharan Africa, the absence of such information creates challenges for evidence based policy. The absence of evidence is in fact a global challenge with only a small number of high-income countries having adequate data on employability (Ibid).

This research therefore sought to establish the perception of employers in the South African construction industry on the level of preparedness of university graduates entering construction practice. Three measures were used to assess the level of graduate preparedness. Firstly, a single item measure, where respondents were asked to rate their extent of agreement, was used. Secondly, respondents were asked to rate several items which comprise of skills, knowledge and competences desired in construction graduates and an aggregate score was computed from the items. Thirdly, respondents were asked to rate attributes which make a good construction graduate. In achieving the objective, the paper first presents a background to the research by reviewing literature on deficiencies and employability of construction graduates generally and in South Africa in particular. The methodology adopted for achieving the objective is then presented and the results analysed and discussed after which conclusions are drawn.

2. Background

There has been widespread concern about the extent to which university graduates are ready for the workplace. The construction industry has equally expressed displeasure at the quality of graduates entering the industry. For example, while analysing the perception of the Ghanaian construction industry on the performance of industry entry level graduates, Ayarkwa et al. (2011) noted that graduates lacked practical building knowledge, problem solving skills, communication skills (inter-personal skills in generally) among several other skills and competences. Love and Haynes (2011) equally noted the absence of all these skills and competences in a survey of construction manager and construction companies in Australia.

Shafie et al. (2014) also reported a gap in the competences of construction graduates in Malaysia.

The competence gaps identified among the construction graduates have an effect on the employability of the graduates. Employability has been defined as gaining employment, maintaining employment and obtaining new employment if required (Lees, 2002 citing Hillage and Pollard, 1998). Harvey (1997, cited in Lees, 2002) defined employability as the propensity of graduates to exhibit attributes that employers expect will be necessary for future effective functioning of their organisation. Employability and employment differ in that employment is only about having a job while employability is possession of the qualities needed to get a job and maintain and progress in the workplace (Lees, 2002; British Council, 2014). Employability therefore depends on the possession of relevant knowledge, skills and attributes and how these are used and presented to potential employers (Lees, 2002).

Copper and Lybrand (1998, cited in Lees, 2002) suggested that employability skills fall in four broad areas of traditional skills, key skills and personal attributes, knowledge of organisations and how they work. Quite similarly, Zou (2008) classified the employability attributes into three categories of attributes, skills and knowledge (ASK) shown in Figure 1. Employers are generally satisfied with the disciplinary knowledge of graduates but perceive significant weaknesses in information technology skills, reliability and transferable skills such as team working and problem solving (British Council, 2014).

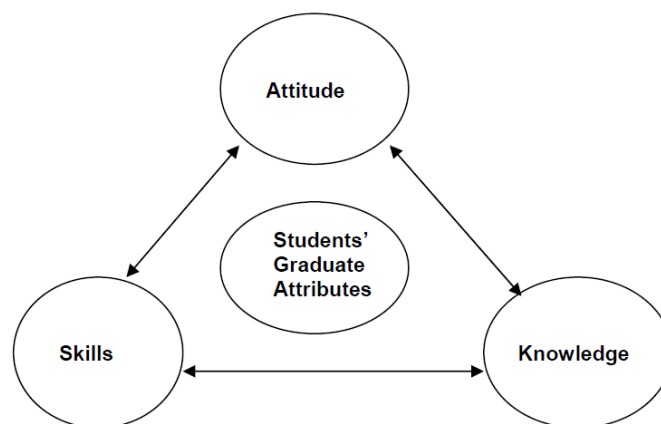


Figure 1: ASK Acronym for Graduate Attributes (Zou, 2008)

The range of skills, competences and knowledge areas identified as important for construction graduates is very large. While assessing employers expectations of the performance of construction graduates, Davies et al. (1999) found that strong interpersonal skills, team players who can also lead a team, information technology, language ability, good commercial awareness, problem solving skills among others were the skills employers expected from graduates. Shafie et al. (2014), while assessing views of employers and expectations of soft skill competences of quantity surveying graduates in Malaysia, identified communication skills, problem solving skills, leadership, team work, professional ethics and moral self-confidence as skills necessary for quantity surveying graduates. Technical skills like measurement, contractual aspects and project management among other competences are also necessary for a well

prepared quantity surveying graduate (Ibid). Adams (1998) established that important topics for contractors in developing countries included accounting and financial management, entrepreneurial studies and project management among many others. Ahmed et al. (2014) identified five skills as important for construction management programmes and these are health and safety regulations, interpreting contract documents, listening ability/giving attention to detail, knowledge of building codes and regulations and time management. Acheampong (2013) and Sedighi and Loosemore (2013) also reported deficiencies in construction graduates.

Inadequacies in the relevant skills, knowledge, competences and attributes desirable in construction graduates have been reported in the South African construction industry. For example, while assessing the performance of diplomates and graduates entering the South African construction industry Smallwood and Emuze (2011) noted that the perception of industry is that the performance is almost inadequate in every learning outcome. The biggest gaps were found in project and site management, construction technology and skills, knowledge of the importance of key issues in construction, communication, people skills, leadership, problem solving and team work. In a survey on the difference between perceptions of importance attached to different skills by graduate employers in South Africa and the employers' level of satisfaction with the actual skills of graduates the British Council (2014 citing SAGRA Survey, 2013) also reported deficiencies in graduates employability albeit not specific to the construction industry. Significant deficiencies were reported in all skills surveyed including willingness to learn, team working, problem solving, interpersonal skills, commitment, proactivity, oral communication, flexibility, planning, numeracy, self-awareness, self-promotion, customer orientation, leadership, networking and business acumen. The graduates were perceived to be well prepared in IT/Computer literacy and foreign language.

Producing graduates who are employable requires the delivery of a university academic experience which imparts the relevant knowledge, skills and attributes that define employability in any particular field. Lees (2002) posited that it is likely that employer's criticisms of the weaknesses of graduate recruits are not necessarily resulting from failure in the curriculum but rather a failure in the transfer process. Lees further suggested that chosen teaching methods assist students to develop the employability skills to varying limits. Ahmed (2014) concluded that an integrated curriculum presenting the distinct parts of the construction process synergistically in a project environment is likely to equip graduates with better construction project management skills.

Notwithstanding the literature suggesting that graduates lack employability skills, Davies et al. (1999) concluded that graduates are actually not as poorly-prepared for the workplace as would be suggested by anecdotal evidence from employers. The British Council (2014) also noted that there is rather weak evidence suggesting that there is a gap in skills between the skills which the graduates possess and the ones that are required in the job market.

3. Research Methodology

A self-completing questionnaire was favoured firstly because the survey was preliminary and conducted to validate the extent of the problem of inadequately prepared graduates in the South African construction industry and since a census was not possible due to the very large number of construction industry practitioners. Graziano and Raulin (2007) suggest that it is appropriate to conduct a survey rather than a census unless the population of interest is small.

3.1 Population and Sampling Technique

Practitioners in the South African construction industry including Quantity Surveyors, Construction Managers, Construction Project Managers, Civil Engineers and Architects were targeted for inclusion in the sample. The respondents were drawn from a purposive sample of Master Builders Association (MBA) members in two of their regions. The selected regions were MBA Kwazulu-Natal (KZN) which covers the province of KZN and MBA North which covers Mpumalanga, North West and Limpopo districts of South Africa. While the MBA registers contractors of different specialisation, only contractors registered in the general contractor category who had valid email addresses on record were targeted for inclusion in the sample because they are more likely to employ graduates of Quantity Surveying, Construction Management and Architecture. While a random sample including all the different MBA regional offices would be more appropriate for external validity and therefore generalisation (Bryman and Bell, 2003), a purposive stratified sampling technique was instead favoured because of the exploratory nature of the research and the convenience of dealing with the selected MBA offices. Greenfield (2002) suggests that it is acceptable to use a non-probability sampling technique when access to elements in a population is prohibitive. However, it should be noted that the resulting sample may contain bias and therefore affect external validity and consequently reduce the power of generalisation (Bryman and Bell, 2003).

3.2 Survey Instrument and Data Collection

The questionnaire was designed to investigate the respondents' perception of the level of preparedness of the graduates from traditional South African universities and universities of technology whom the respondents had worked with. The questionnaire also sought to establish the extent to which the university education programme prepared graduates for specific educational attributes. In achieving these objectives, two scales were prepared. The first scale had 31 items with phrases about characteristics of graduates which were measured using a five point Likert scale with 1 = "Strongly Disagree", 2 = "Disagree", 3 = "Neutral", 4 = "Agree" and 5 = "Strongly Agree". The characteristics ranged from personal attributes to knowledge possessed by the graduates. The second scale was used to measure the extent to which university educational experience impart a range of attributes desirable in graduates using 22 attributes.

3.3 Implementation

The survey instrument was circulated to the target sample as an e-mail attachment by the MBA using their register of general contractors with a letter explaining the survey, its use and noting that participation was completely voluntary, results would be aggregated and therefore no individuals would be linked to any specific response and that respondents had the right to accept or refuse participation. While the use of questionnaires attached to e-mails is not yet common place, web-based survey instruments are becoming common place. Denscombe (2006) and Calbring et al. (2007) concluded that there is little evidence of a mode effect linked to web-based questionnaires compared to paper based ones. While a questionnaire attached to an e-mail is different from a web-based survey, they share a number of commonalities including the electronic nature of the interface as opposed to a paper interface and the use of the internet to communicate the responses among others. It can therefore be assumed that the two modes of survey dissemination should share similar advantages and disadvantages and can be concluded also that evidence suggests that the use of e-mail in surveys does not create any errors or biases that can be attributed to the mode of questionnaire administration.

4. Results and Discussion

The respondents were general contractors registered with the MBA KZN and MBA North who employ university graduates in construction. A total of 55 responses were received and analysed.

4.1 Graduate Preparedness

Table 1 indicates that the construction industry practitioners do not feel that construction graduates entering the South African construction industry are adequately prepared for the construction industry practice. The average score of 2.40 from the scale ranging from 1 through to 5 with 1 being strongly disagree, 2 being disagree, 3 being neutral, 4 being agree and 5 being strongly agree that the graduates are well prepared for construction practice indicates that the employers are not satisfied with the work readiness of the graduates upon entering the construction industry practice. This finding is consistent with other findings from South Africa such as from Smallwood and Emuze (2011) and also from the British Council (2014) and Shafie et al. (2014) and Aryakwa et al. (2011).

Table 1: Descriptive Statistics for “Graduates are well-prepared for immediate engagement with the world of work”

	N	Mean	Std. Deviation
Graduates are well-prepared for immediate engagement with the world of work	55	2.400	0.852

Rather than rely on a single item measure of the concept of industry perception of graduate preparedness, the 31 item scale was analysed. Firstly, the 31 items were tested for unidimensionality and to find the factors which consistently measure the same underlying

construct. Cronbach's alpha was used and a resulting score of 0.908 was achieved after deleting some items so as to achieve the highest possible reliability index shown in Table 2. Cronbach's alpha measures the reliability of a data set which represents the degree to which the observed values measures the 'true' value and is thus error free (Hair et al., 1998). Weimer (1987) defines reliability simply as the probability that the estimate is correct. The computed Cronbach's alpha of 0.908, shown in Table 2 suggests that there is a 90.8% probability that the error of the estimate is at most 0.05.

Table 2: Reliability Statistics

Cronbach's Alpha	N of Items
0.908	18

The descriptive statistics of the 18 selected items measuring the construct of graduate preparedness are shown in Table 3. Based on the mean scores, respondents felt that graduates have a desire to learn as indicated by the mean score which tends towards the agree score of four. The desire to learn new things is contrary to the report by the British Council (2014 citing SAGRA Survey, 2013) on the employability of South African graduates who were reported to be reluctant to learn. However, the reported survey was aggregating results from different disciplines. The findings here therefore suggest that the construction graduates differ in their propensity towards learning new things as compared to the rest of the South African graduate population.

The rest of the items have mean scores tending towards three indicating that the respondents do not feel that graduates perform well in these areas. Other findings have indicated deficiencies in most of these areas. For example, Ayarkwa et al. (2011) found that graduates lack practical building knowledge in the Ghanaian construction industry consistent with the item indicating that graduates have inadequate knowledge of construction. Graduates lack the ability to define and solve problems consistent with the item indicating that graduates are unable to propose solutions to problems and substantiate and justify their position (Ibid).

Table 3: Graduate Preparedness Descriptive Statistics

	N	Mean	Std. Deviation
Graduates demonstrate a desire to learn new things	36	4.056	0.754
Graduates are able to work in a multi-cultural environment	20	3.650	0.813
Graduates are able to work in a team	55	3.455	0.835
Graduates are able to work methodically to finish an assigned task	12	3.417	0.996
Graduates conduct themselves ethically at all times	55	3.382	0.757
Graduates are able to learn on their own/autonomously	20	3.250	0.786
Graduates are knowledgeable about health and safety	12	3.167	0.835
Graduates are technically well-skilled	55	3.164	0.996
Graduates are assertive and willing to accept responsibility on projects	20	3.150	0.875
Graduates understand consequences of their actions	20	3.150	0.988

Graduates are able to communicate effectively in writing	55	3.127	1.139
Graduates are assertive	12	3.083	1.084
Graduates are able to communicate effectively orally	55	3.055	1.061
Graduates are respected by their seniors/those they report to	12	3.000	0.953
Graduates possess an adequate set of skills for professional practice at entry level	20	2.750	1.020
Graduates are able to propose solutions to problems and substantiate and justify their position	55	2.673	1.037
Graduates understand the financial aspects of construction	12	2.667	1.231
Graduates have adequate knowledge of construction	55	2.618	0.972

Table 4: Graduate Preparedness Descriptive Statistics

	N	Mean	Std. Deviation
Average	55	3.157	0.633
Valid N (listwise)	55		

While a total of nine items were not considered in computing the aggregate score of Graduate Preparedness, they were notwithstanding individually compared with the computed Graduated Preparedness score in order to identify any trends among the deleted items. The average scores of each of the deleted items are shown in Table 5. All the deleted items fall below the agree point except for the item “Graduates are able to use technology and software packages” to which the respondents agree that the graduates are well prepared to do. This finding is consistent with Ayarkwa et al. (2011) on construction graduates in Ghana and with the British Council (2014 citing SAGRA Survey, 2013) on South African graduates generally who found that the computer literacy of graduates was acceptable to employers.

Employers feel that graduates are not well prepared in the rest of the items shown in Table 5. Most of the deficiencies are consistent with several other findings.

Table 5: Descriptive Statistics

	N	Mean	Std. Deviation
Graduates are able to use technology and software packages	12	4.083	0.515
Graduates conduct themselves ethically at all times	55	3.381	0.757
Graduates are able to defend themselves in terms of a position they take which might be different	12	3.250	0.754
Graduates always conduct themselves professionally	55	3.182	0.905
Graduates respect authority	12	3.167	1.030
Graduates demonstrate sensitivity to needs of others they interact with at work	20	3.150	0.671
Graduates are able to read and understand documents	12	3.000	0.853
Graduates understand the legal and risk aspects of construction such as standard forms of contract	12	2.667	0.888

Graduates understand punctuality and are punctual themselves	12	2.583	0.669
Valid N (listwise)	12		

4.2 Graduate Attributes

Respondents were asked to state the extent to which they agree that the university experience offered to graduates imparts in them attributes desirable in a graduate. The resulting reliability index for the construct of graduate attributes is shown in Table 6. The attributes of the graduates exhibit a high level of internal consistency.

Table 6: Reliability Statistics

Cronbach's Alpha	N of Items
0.934	22

The descriptive statistics for the scale of graduate attributes are presented in Table 7. The mean scores range from 3.40 to 2.40 indicating a general disagreement that the graduates possess the desired attributes.

Table 7: Graduate Attributes Descriptive Statistics

	N	Mean	Std. Deviation
Employable	46	3.435	1.128
Knowledgeable	46	3.413	0.777
Responsible	45	3.356	1.004
Adaptable	46	3.304	0.963
Socially responsible	46	3.283	0.958
Lifelong learner	46	3.283	0.981
Planner	46	3.239	1.099
Pro-active	46	3.217	1.073
Independent thinker	46	3.217	1.073
Skilled professional	45	3.133	1.057
Culturally aware	45	3.133	0.991
Communicator	46	3.130	1.024
Problem solver	46	3.087	1.029
Critical thinker	46	3.087	1.112
Informed	46	3.087	1.112
Human skills	46	3.044	0.918
Forward thinker	46	3.000	1.174
Leader	45	2.911	0.949
Entrepreneur	46	2.848	0.942
Practical	46	2.848	1.010
Visionary	44	2.773	1.138
Negotiator	46	2.413	0.909
Valid N (listwise)	41		

A new variable measuring the graduate attributes was computed from the mean scores of all the individual items investigated. The resulting descriptive statistics for the aggregate variable are presented in Table 8 which also shows that the respondents are not altogether satisfied with the university graduates entering the construction market.

Table 8: Descriptive Statistics

	N	Mean	Std. Deviation
Graduate Attributes	47	3.117	0.692
Valid N (listwise)	47		

4.3 Associations among the Variables

In order to identify any relationships among the variables, the variables were tested for associations among them. Firstly, a normality test was performed to establish whether to use parametric or non-parametric tests of association. The Kolmogorov-Smirnov statistic is used to test for normality for a sample size exceeding 2000. The Shapiro-Wilk test (shown in Table 9), which tests the null hypothesis that the data are drawn from a normal distribution for a sample size not exceeding 2000, suggests that the “Graduates are Well-prepared for Immediate Engagement” data does not follow a normal distribution while the “Graduate Attributes” data and “Graduate Preparedness” data follow a normal distribution. Since one of the variables does not follow a normally distributed, non-parametric tests were preferred.

Table 9: Tests of Normality

	Kolmogorov-Smirnov ^a			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Graduate Preparedness	0.114	47	0.157	0.955	47	0.066
Graduate Attributes	0.069	47	0.200*	0.983	47	0.738
Graduates are well-prepared for immediate engagement with the world of work	0.274	47	0.000	0.865	47	0.000

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

The Kruskal Wallis test, a non-parametric test exploring differences in mean scores, was computed to establish whether the mean scores of the computed “Graduate Preparedness” variable differ significantly with the single variable item which inquired whether “Graduates are well prepared for the immediate engagement with the world of work”. The resulting chi-square statistics ($\chi^2(2, N=55)=13.165, p=0.001$) and the Spearman’s rho correlation statistics ($r=0.629, N=55, p=0.000$) suggest that the two variables are associated with a fairly strong positive correlation.

The Kruskal Wallis test statistics were also computed relating the computed variable of “Graduate Preparedness” with the computed variable of “Graduate Attributes” to establish whether the two variables are also associated. The resulting chi-square statistics ($C^2(3, N=47)=20.817, p=0.000$, and Spearman’s rho correlation statistics ($r=0.764, N=47, p=0.000$) suggest that the perception of graduate preparedness is strongly associated with the perception of the attributes possessed by the graduates with a very strong correlation coefficient.

The three measures used to assess level of preparedness of construction graduates for construction practice all correlate strongly and significantly with each other at an alpha of 0.001. The significant and strong correlations, which confirm that the three measures are related, confirms that the three measures are all valid measures of the perception of the respondents about the level of preparedness of the graduates and also validate the internal consistency of the instrument. The internal consistency of the instrument is also validated by the high Cronbach’s alpha of the three measure shown in Table 10.

Table 10: Reliability Statistics

Cronbach's Alpha	N of Items
0.802	3

5. Conclusions

Employers in the South African construction industry feel that construction graduates entering the construction practice are inadequately prepared by the university education experience they are offered consistent with other findings from the South African construction industry and also from other countries surveyed. All three variables used to assess the perception of employers of the level of preparedness for construction graduates entering the South African construction industry consistently demonstrate that employers feel that university graduates are not adequately prepared for practice.

Skills, knowledge and competences perceived to be lacking in the graduates include knowledge of construction, financial aspects of construction, problem solving, professional practice, oral communications skills, written communication skills, health and safety, self-directed learning, ethics, team work, punctuality, legal and risk aspects of construction, reading and understanding of documents and professional conduct among others. Attributes found to be deficient include negotiation, vision, practicality, entrepreneurial attributes, leadership skills, forward thinking, critical thinking, problem solving, and communication among others. On a positive note, graduates were rated fairly well in the desire to learn and IT skills.

While the scenario regarding the extent to which graduates of construction programmes from South African universities based on the findings of this research looks rather bleak, it is worth noting that the research is based on the perception of employers about the graduates. The results therefore also point to a very highly expectant set of employers who may not adequately appreciate that university programmes need to provide a firm theoretical grounding for the graduates to develop into a career of choice within the industry. Therefore, while it is important

that graduates possess the relevant skills, knowledge, competences and attributes, the employers perception of the relevant extent to which graduates need to demonstrate these at entry level may be overrated. Also worth noting is that other research has established that there is in fact weak evidence suggesting that there are gaps between competences possessed by graduates and those required in the job market.

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Factors Affecting Condition-Based Maintenance in Petroleum Pipelines Operation in Nigeria Oil and Gas Sector

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Abstract

This research paper investigates how maintenance performance measurement is utilised to measure Condition-Based Maintenance (CBM) in petroleum pipelines (PPs) in the Oil and Gas (O&G) industry. The paper is written using the findings of an extant literature review. The paper reviews various concepts of performance measurement (PM) and issues in relation to CBM in the O&G Industry. The paper discusses in-depth, the use of performance measurement in Condition-Based Maintenance in the Oil and Gas industry. The findings highlight the importance of performance measurement in CBM as a system that ameliorates pipelines maintenance and synergises O&G workforce to achieve a well-defined work procedures in CBM. This paper identifies performance measurement as a possible sub-system of strategic maintenance in petroleum pipelines (PPs). Performance measurement is in fact a return to the fundamental concept of CBM, and is a means of ensuring that the lifecycle of PPs is well managed and maintained. Based on the findings of this study, the paper develops a conceptual model for measurement of efficiency of actions in condition-based maintenance in pipelines. In order to improve workers performance, motivation, good information management, collaboration, and

Keywords: Condition-Based Maintenance (CBM); Performance Measurement (PM); Oil and Gas (O&G); Petroleum Pipelines (PPs), Strategy

1. Introduction

1.1 Condition-based maintenance in pipelines

The nature of maintenance work in the Oil and Gas (O&G) sector has change in recent decade from strictly preventive or corrective maintenance to condition-based maintenance as a result of huge increase in the number of petroleum pipelines (PPs) to be maintained. The term condition-based is used to discuss and interpret problem, situation and circumstances causing a particular or whole section of PP disorder, and assist management to decide the maintenance action to be performed. Facility maintenance in the O&G sector require improvement in the strategic and operational function. Because Oil and Gas (O&G) is considered as the backbone of the global economy, which involve a rigorous operation such as: exploration/extraction, refinement, transportation, and marketing of the petroleum products often by petroleum pipelines (PPs) (Duncan and Wang, 2014). There are several ways in which O&G can be transported, e.g. ocean moving vessels, tankers, rail transportation and pipelines. Yet, PPs remain the easiest, economical, resilient and robust way of transporting O&G in the petroleum industry (Ai-Khalill, 2005; Anifowose, 2012; Duncan and Wang, 2014; Shafiqur and Al-Hadhrami, 2014). PPs profitability cannot be overemphasised as it tends to be an indispensable component in the O&G industry (Ossai 2012; Bandinelli and Gamberi 2011). PPs can be defined as an integrated tube used to transport O&G liquid to demand point.

Despite the profitability or value in the use of PPs, PPs has not been without flaws. Equally, industries using pipe either as a storage facility or as a source of transporting O&G may face different challenges (Enyiche2 2011; Qian et al., 2011; Anifowose et al. 2012). Many of the challenges often occur as a result of improper maintenance, vandalism, corrosion or rupture and ageing. For example, ageing pipelines, i.e. those pipelines near the end of their useful remaining life or exceeding their original design life (Anifowose et al. 2012; Ossai, 2012). There is an increasing requirement around the world to defer their replacement or extend their remnant life (Clausard, 2006; Okamoto et al., 1999). Problem within this ageing PPs if unnoticed, can lead to catastrophic consequences at the time of deterioration (Bogue, 2013; Barabadi, 2014). Some example of major pipelines incidences in Nigeria alone include: such as, the 1998 Jesse pipeline explosion in Nigeria that almost claimed an entire village, burning to death over 250 people; the Ijegun 2008 PPs explosion in Nigeria damage more than 15 homes and 20 vehicles as construction workers incidentally broke the underground PPs; and, the 11th July 2015 PPs explosion in Bayelsa State Nigeria killing 12 workers, the 27th March 2016 O&G pipelines explosion killing operators (Aroh et al., 2010, The Guardian, 2015, Punchng.com, 2016). Consider: “it is such examples as the above that necessitate an improvement in the level of PPs”

1.2 Maintenance concepts and Strategies

Certainly, improved maintenance concepts and strategies could guarantee O&G pipelines robustness and reliability. Literature indicates that, improved maintenance has the capability to influence resources or maintenance operation in several monitoring levels (Alabdulkarim et al. 2014; Prajapati et al., 2012). On the other hand, inadequate maintenance plan may trigger

system deterioration and cause disaster (Aboelmaged, 2015). In contrast, Dey et al. (2004) argue that most pipeline workers ensure that during the installation PPs, safety provisions are created to provide a theoretical minimum failure rate for the life of the pipeline. Kadafa (2012) argues that, despite the safety provision in place, several failures have been inevitable in PPs operation. Hence, strategic maintenance is important in the improvement of PPs maintenance. It can reasonably be argued, therefore that issues of strategic maintenance cannot be overlooked in the process of pipelines maintenance. Also, the role planning and adequate implementation play in the achievement of pipelines maintenance projects or the methods by which they are obtained is well documented in the “literature review”. See (Oliver Schwarz 2005; Paranjape et al. 2006; Greenough and Grubic 2010; Prajapati et al. 2012; Platfoot 2014; Goyal and Pabla 2015). Beside the practice of CBM, there is a need to understand other maintenance function and what constitute pipelines maintenance and how to perform the assigned task successfully and this is discussed in the next section

2. Maintenance Types and Practice

The oil and gas (O&G) industry often practice several pipelines maintenance types in order to prevent pipelines from failure (Achebe et al., 2012; Agbakwuru, 2011; Gomes et al., 2013). Most of the maintenance practice include: preventive maintenance, corrective maintenance, turn around maintenance, reliability centre-maintenance, total productive maintenance, risk-based maintenance, shut-down maintenance, opportunistic maintenance, computerised maintenance management system, total quality maintenance and condition-based maintenance (Bousdekis et al. 2015; Fraser et al. 2015). However, preventive and corrective maintenance describes a wide range of activities designed and performed in order to improve the overall reliability and availability of a system (Moghaddam and Usher, 2010). Regardless of the specific pipelines system, preventive and corrective maintenance activities can be categorised in one of two ways, which is either repair or replacement (Öhman et al., 2015; Platfoot, 2014; Van Horenbeek and Pintelon, 2014). Preventive maintenance has been derived from a level of repair analysis to determine the maintenance allocation for a given system or subsystem (Prajapati et al., 2012). Corrective maintenance is often referred to as run to failure practice or maintenance task performed after failure has occurred or in the process of occurring. Corrective maintenance constitutes repair, refurbishment or replacement of sectional breakdown, or other remedial work to restore pipelines system to its original state as it was in new condition (Prajapati et al., 2012; Reza Golmakani and Fattahipour, 2011).

Equally, opportunistic maintenance, RCM, risk-based maintenance and other maintenance types are often seen as extra maintenance activities performed to enhance the overall performance O&G facility. Their activities consist of inspection, cleaning, lubrication, adjustment, alignment, and replacement of O&G pipelines facility that is wear-out or faulty. However, aforementioned maintenance types are usually done to elongate PPs lifespan or retain their serviceability (Al-Khalil et al. 2005; Liu et al. 2010; Sahraoui et al. 2013; Duncan & Wang 2014). Despite the numerous maintenance types, corrosion, sabotage, improper maintenance still persists. The prevailing issues in the Nigerian context are corrosion attack, improper maintenance and

sabotage. Corrosion fatigue consists of cracking of material due to changing cycle, stress or as a result of corrosive environment. Improper maintenance issues may occur as a result of poor management, sociotechnical inordinate behaviour, social factors, and lack of motivation, poor communication within upstream and downstream section, lack of technical knowhow and the use of low quality materials. Sabotage involves third party meddling and obliteration of pipelines reliability (Bagkavos, 2008). However, this study assumed that sabotage and obliteration caused by third party may prompt corrosion outbreak and other unwanted issues in pipelines maintenance. These issues often interrupt the firm approach in the practice of preventive or corrective PPs maintenance activities in the Nigeria O&G sector.

Prajapati et al., (2012) argue that, adopting strictly preventative or corrective maintenance approach leads to inefficiencies in the use of manpower, subsequently causing downtime of PPs systems, economic loss and other wastefulness. At the heart of any pipeline integrity management system (PIMS) is having an understanding of the likely condition of a pipeline and confidence in the data generated from any inspection programme conducted to validate this understanding (Clausard, 2006; Fink et al., 2004; Okamoto et al., 1999). Based on the data generated on PPs inspection programmes, an Operator can go forward and make decisions related to the current and future integrity of a pipeline, remaining life assessment with the help of condition-based maintenance philosophical viewpoint to appropriate corrective and preventive maintenance action (CAPA) and to monitor activities that will improve pipelines performance.

CMB can be defined as an instrument that managers use to underpin efficiency and effectiveness of action in pipelines maintenance by helping managers to deal with issues related to functional safety, environmental and operational failure modes. CBM helps managers to plan and formulate a workable strategy through historical and current data (Al-Najjar, 2012; Fraser, 2014; Prajapati et al., 2012). In this instance, CBM seeks to discover the root cause of the failure and performs the detailed analysis of the reliability of the system components and the system as a whole (Al-Najjar, 2012; Bousdekis et al., 2015; Prajapati et al., 2012). Bousdekis et al. (2015) argue that, CBM can only detect emerging failures before their occurrence through diagnostic and prognostic techniques. CBM uses condition monitoring techniques to assess, control and investigate pipelines whether a problem exists and to determine the life cycle usefulness before failure occurs (Garg and Deshmukh, 2006; Prajapati et al., 2012).

Furthermore, Prajapati et al. (2012) state that, CBM enables the automotive, aerospace, military, and other industries to understand values of maintenance network bandwidth, data collection and retrieval, data analysis, and decision support capabilities for large data sets of time series data. In contrast, CBM forms the basis of all types of maintenance (Zhou et al., 2015). For instance, CBM function can be done either as in preventive/corrective maintenance, or condition monitoring. Consequently, the real uptake and implementation of CBM often improve the maintenance concept in the O&G industry. As a result, a comprehensive maintenance definition should embrace the CBM philosophical view. Taking this into consideration, maintenance is defined as a process of assessing assets condition and to know the current state and improve its condition using CBM elements to determine the necessary maintenance either about preventive, corrective, reliability centre maintenance or other maintenance actions needed to underpin or improve PPs condition monitoring in order to possess the assets.

Moreover, the effectiveness of CBM requires a comprehensive maintenance management system. Being that the enterprise-wide information management and business planning has become a norm rather than an exception (Garg and Deshmukh, 2006). Combined with a review of the pipelines maintenance management activities, e.g. review of internal and external issues in pipelines maintenance and management, CBM monitoring correlation with the inspection findings, will enable the integrity management strategy to proactively diagnose the likely causes of corrosion and discuss other related issues. On this basis, individual maintenance performance can be improved using lesson learned in order to obviate unwanted event that may decline PPs performance. Based on the determined corrosion or sabotage rates, accurate monitoring and prediction of future repair together with mitigation requirement can be determined via CBM historical data.

The search for materials and identification of issues using extant literature involved a rigorous process of selecting materials from databases such as: Emerald Insight, Google scholars, Science direct and Scopus. Performing combination of key words like performance measurement approach in pipelines integrity management, performance measures in condition-based maintenance in pipelines, maintenance performance measurement in the O&G industry result to many qualitative and quantitative materials. Applying the grounded theory approach, the materials gathered were narrowed down and focus on qualitative materials pertinent to this study. The Glaser and Strauss 1960s approach enable this study to perform constant comparison of different pipelines issues and incidences, to assess individual perceptions about pipelines maintenance, the role performance measurement plays in the maintenance of PPs. Also, the grounded theory approaches enable a clear identification of the key issue affecting CBM in pipelines. The process of identifying the discrepancies, contradictions, gaps in the CBM in pipelines activities and to formulate the emerging consensus that will improve the maintenance process also involve another rigorous process.

The practical relevance about grounded theory is that researchers do not know the outcome, until it emerges by investigating issues. However, the procedures of assessing worst-case hypothetical conditions and for the analysis of the consequence of any given pipelines failure are beyond the scope of this paper. Besides, pipelines failure and maintenance hypothetical characteristics and consequences vary with each pipelines sizes, also the environment vary were pipelines operation are done on daily basis (Anifowose et al., 2012; Okoh and Haugen, 2014; Shukla and Karki, 2016; Sylvestor et al., 2004). Pipelines failure and related issues tends to be a global problem. Though, several rules and regulation are in place to ensure adequate performance of CBM in pipelines. But, in the current time, the full benefits of CBM in pipelines maintenance can be realised through performance measurement plan do check act (PDCA) model, a techniques that enable managers to assess the effectiveness and efficiency of action in facility maintenance engineering/management. Undoubtedly, performance measurement approaches has enable some industries to outperform their equals in business. The next section will be discussing the intrinsic values about performance measurement

3. Performance measurements

There is a need for manager to analyse CBM activities in PPs and how to utilise the full benefits of CBM in PPs maintenance. Equally, literature review justified the need to perform measurement with an adages “you can’t manage what you can’t measure and what get measured gets done” these elements underpin PPs maintenance managers to safeguard working environment. The change in the operating context cause maintenance managers to concentrate on effectiveness of actions within PPs routes. Performance indicators are needed to give maintenance managers in charge of operation a qualitative information on the extent to which these goals are reached and the next actions to take to improve CBM operations. Performance indicators are a means to achieve maintenance control, so that maintenance costs can be reduced, productivity can increase, safety of the process can be achieved and environmental regulations can be fulfilled (Arts et al., 1998). For instance, in the UK, Liyanage and Egbu, (2008); Njuangang et al., (2015) develop some key performance measurement improvement concept to underpin the improvement of hospital facility maintenance management. Similarly, Parida et al., (2015) exemplify the importance of performance measurement across industries, whit emphasis on performance indicators, leading and lagging indicators, and the identification of “performance drivers and killers”, in maintenance operation. Moreover, performance measurement often involves a comprehensive approach linking strategy to action, motivating employees, supporting budget and controlling resources in order to overcome the strictly approach to the traditional practice of the engineering maintenance management in the industries. In this aspect, performance measurement allows benchmarking process to be performed in order to eliminate the out-dated management style, which does not support the current technological improvement in pipelines maintenance (Al-Najjar and Kans, 2006; Kutucuoglu et al., 2001; Lee et al., 2013; Simões et al., 2011). Another area to be addressed through performance measurement is the sociotechnical inordinate behaviour, a factor that often limit the effectiveness of action in pipelines maintenance. In fact, social issue can significantly influence maintenance performance. For example, pipelines conflicts between department and poor collaboration might prevent operators from passing on important information.

Inadequate information often result to neglect or abandonment of PPs maintenance in long-distance location. Most time, it lead to corrosion attack, leakages and environmental depredation. Also, causing counter accusation, political oversight and communities meddling due to environmental depredation. Though, literature indicates that issues like this can only be overcome through performance measurement. Hajjari, (2012) explain that, at the organisational context, maintenance contains several aspects that can affect the maintenance activities and cause undesirable adverse effect in maintenance processes. Therefore, performance measurement is required to refine the maintenance culture and to lead in the process of planning and monitoring maintenance. Performance measurement approach can be used to determine assigned job and monitor the efficiency and effectiveness, improve communication system, improve decision-making process and assess workers behaviour. Even in the decommissioning process when a particular route or section is no longer viable or required performance measurement can support CBM activities to achieve success in the operation.

Performance measurement practice can be plausible when management utilised the key performance indicators to assign task and monitor individual performance. Individual performance can also be monitored through a defined work order model as shown in table 1. The essence of work order is to guide operators about the maintenance activities/action and together with the role individual must perform in order to achieve target.

Table 1: CBM detailed work-order guide (source: (Platfoot, 2014))

PM function	Condition based maintenance pipeline work-order Mandatory	Documentation guide
Elements in work order	Date work requested, KPI to prioritise work; status of work, open, approved, work in progress, completed or cancelled, area to be worked on/location of work, specification of work to be done	Date work closed; date work scheduled commence, actually date work commenced, amount of resource/crew, summary of maintenance job plan
Work description or specifying the type of work	Work order type; priority of work order (e.g. emergency, periodic inspection, constant monitoring etc.).	Maintenance activity type; priority of original request Total
Cost of work	Actual amount/Prorated	Total cost (estimated and actual), labour hours (estimated and actual), materials and other miscellaneous costs/ coherent cost code
Performance evaluation	Monitor performance	Recommend

Applying the performance indicators or maintenance performance indicators according to (Parida et al., 2015), the work order can be fully defined and utilised. The issues of vagueness and inadequacy about measures can be obviated through this method.

Given a clear focus in the measurement of efficiency and effectiveness of pipelines maintenance within the upstream and downstream pipelines distribution network. In this aspect, performance measurement indicators enable managers to compare the actual operating conditions with a specific set of reference conditions and to ensure managers achieve target in the following ways:

- Establish solid technical justification for using the set objective and articulate the reason for not using other objective for assessment techniques to assess the pipeline section (Nidd et al., 2007).
- Establish active data management system to ensure security of data that will allows integration and manipulation for further improvement (DeWolf, 2003)
- Ensure that all data provided are sufficient for long-term planning and helping to achieve acceptable statistical conclusions (Nidd et al., 2007)
- Monitor the technical function to ensure that the collected data and results are accurate within acceptable industry tolerances.

- Ensures that all personnel involve are fit-to-work, trained and qualified and all certifications are documented, perhaps organise periodic medical check-up for workers.
- Ensures that CBM activities are achieved in a timely manner.

Literature indicates that, performance measurement and CBM support decision-making. Amalgamating the two elements will holistically address facility maintenance issues without discrepancy and helping to incorporate and regulate the relevant maintenance elements into the organisational management cycle. In the aspect, Armstrong (2006) exemplifies five basic performance measurement elements, which includes: agreement (i.e. incorporating operators to synergy in order to achieve organisational goals), measurement of efficiency and effectiveness, quality data collection and feedback, positive reinforcement and dialogue performance output. In this aspect, performance measurement can be fully utilised in CBM in pipelines as shown in figure 2.

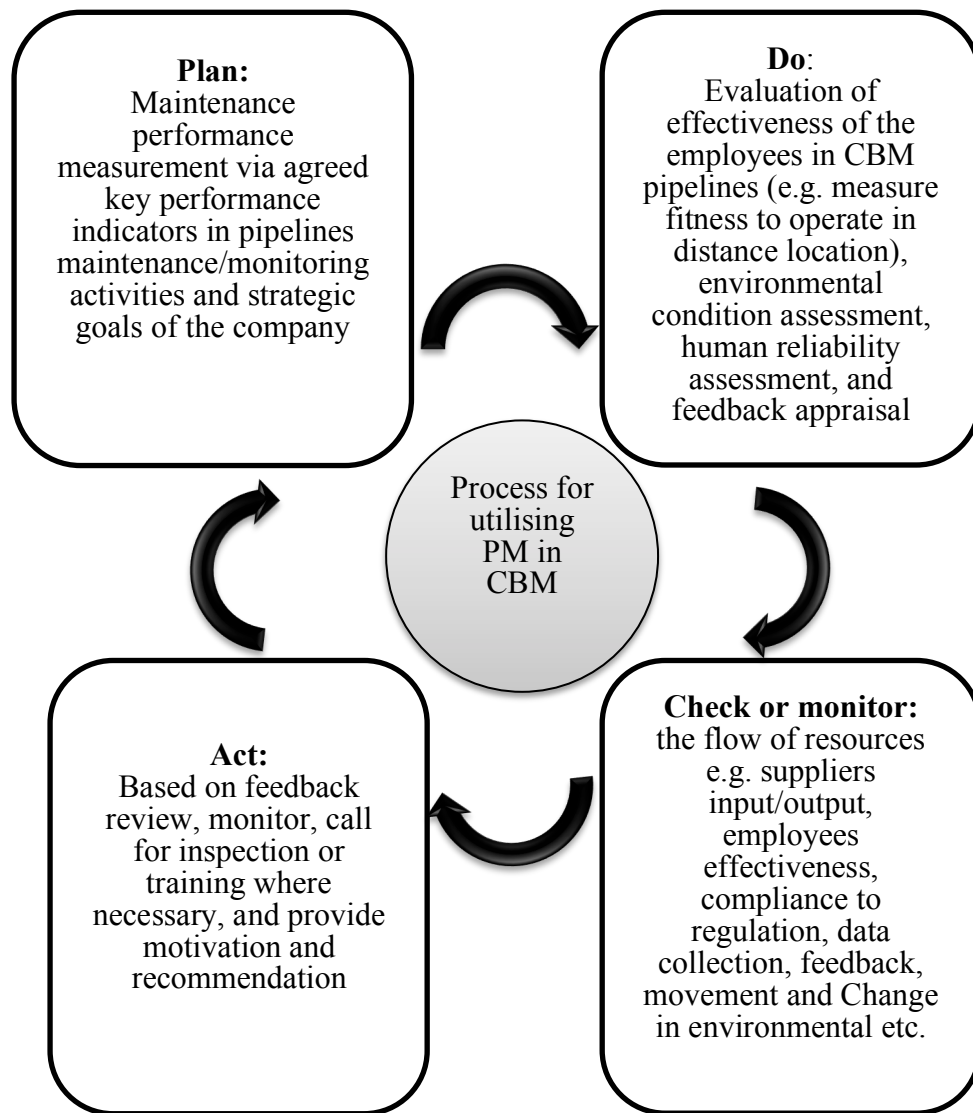


Figure 1: Condition-Based Maintenance Plan-Do-Check-Act model

In addition to the work-order as discussed in Table 1 above, measurement of performance can be realised through the PDCA model. The PDCA facilitate the work-order procedure, by help operators to understand their role in the pipelines integrity management programme before the performance of that role can be fairly assessed (Huprich, 2008; Kutucuoglu et al., 2001b; Parida and Chattopadhyay, 2007; Simões et al., 2011). Though, individual or maintenance team goals should to be defined before the commencement of work, to enable the field supervisor aligns the operators' objectives with the organisational goals (Huprich, 2008).

In pipelines maintenance, operators' role cannot be overemphasised, because they provide continuous assessment and feedback for the improvement of goals and to determine individual performance in PPs maintenance. In this form, PDCA can positivity influence measure, to determine safety compliance and ensuring adequate maintenance within the upstream and downstream sector is achieved. The PDCA justify the link between CBM and performance measurement as a single entity, their separation may result to catastrophic effect in pipelines maintenance. The union are power for decision-making in pipelines maintenance. Also in terms of monitoring, repair, replacement and improvement and decommissioning of pipelines system. Based on the different categories of issues discussed, the study can conclude that the identified issues can be used in extracting new performance indicators for condition-based maintenance in pipelines (i.e. extra indicators has been added to extant performance measurement indicators that is currently in operation for driving the performance of pipelines maintenance plan). Further research may consider defining contextual issues using real case scenarios for deriving performance measurement in pipelines maintenance project.

4. Conclusion

This paper exemplifies the importance of performance measurement and how to utilised performance measurement in condition-based maintenance in pipelines in various way. For instance, the application of plan-do-check-act (PDCA) and work-Oder in complex pipelines maintenance job and to monitor issues opposing pipelines performance. Another reason for this research is to establish plausible performance measurement method that will underpinning pipelines integrity management and justify values created by means of utilising performance measurement indicators for the improvement of facility maintenance and environmental protection at workplace.

The study also demonstrates the influence of using grounded theory to critically examine issues that requires improvement. It is clear that the combination of CBM and performance measurement is beneficiary and valuable, it rewards pipelines deficiency positively they merge corrective, preventive, and condition monitoring types of maintenance to address pipelines issues in a logical manner. As the research develops, the details of the model will be expended, and further study will be exploring issues relating to maintenance model being implemented that is designed for use within pipelines maintenance management involving life project scenario.

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Research Roadmap for Safety and Health on Construction Sites

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Abstract

The proceedings paper details the initial roadmap process, data collected, and summarizes steps forward for the Working Commission on Safety and Health in Construction (W099) to produce a complete research roadmap. A preliminary consultation report was developed in 2013. Data collection included an initial web-based survey sent to W099 members and registered W099 2015 conference attendees. The survey was completed in August before the September conference. At the conference special plenary sessions were organised to define and shape the research roadmap and goals. Seven brainstorming sessions were held around themes important to the CIB W099 and building off the survey results. The sessions were audio recorded, transcribed, and summarised. Future directions for finalisation of the roadmap are discussed with the goal of validating the roadmap during a workshop at the 2016 World Building Congress.

Keywords: Roadmap, research, safety, health, construction.

1. Introduction

Occupational health and safety (OHS) is the science of the anticipation, recognition, evaluation and control of hazards arising in or from the workplace that could impair the health and well-being of workers. (Finneran and Gibb, 2013). Occupational health and safety is both an interdisciplinary and a multidisciplinary science clearly connected to and built on many other disciplines (Aven, 2014). Aven further contends safety science is also a discipline in itself. A 2014 Special Issue of the journal *Safety Science* sought to define, better understand, and operationalise safety science. Various leading safety researchers provided input. Hollnagel (2014, pg. 24) for example, writes that “the object of safety science is accordingly how people are able to provide the required performance under expected and unexpected conditions alike.” Hale (2014, pg. 67), discussing research in safety science comments that “Practitioners and their financial masters are too willing to follow safety intervention fashions and to accept anecdotal evidence that something will work, rather than asking for that more rigorous levels of proof to raise the probability that their investment is worthwhile.”

Globally, construction is one of the most hazardous industry sectors with many thousands of workers being killed and seriously injured each year. While some regions have been making progress over the years there is still a long way to go to reach the vision of an industry where people return home at the end of a shift healthier than when they arrived (Finneran and Gibb, 2013).

There exists a great need to frame a research and practice oriented path forward in construction safety and health. CIB W099, the Working Commission on Safety and Health in Construction, is taking up this challenge alongside many CIB Working Commissions with the goal of positively affecting the global construction community. This proceeding paper is not a research roadmap. Rather, this is the summary of the initial discussions about the development of the CIB W099 research roadmap. Therefore, the paper does not contain a critical analysis of all the data.

2. Background

The goal of CIB W099 is to complete a research roadmap to better engage with and impact the global construction industry. The Roadmap has four specific aims:

1. To identify research which is important in construction safety and health.
2. To identify research gaps in the field of construction safety and health.
3. To suggest research priorities in the field of construction safety and health.
4. To identify ways that CIB W099 can contribute to these research priorities in the next 10 years.

3. Methodology

The W099 research roadmap is currently in process and is building off a preliminary consultation report (Finneran and Gibb, 2013). This proceeding paper reports on the data collected through December 2015 and specifically two sources of data. The first was an on-line survey taken in August before the most recent W099 conference and meeting in Belfast. The survey was sent to W099 members and registrants of the September Belfast W099 conference. They were asked to forward the survey on to colleagues and encouraged specifically to send to colleagues in industry and governmental agencies. The second data source were the brainstorming sessions held at the Belfast W099 conference which followed up on the on-line survey summaries.

On-line Survey

In the survey we asked almost primarily opened ended questions to allow respondents to write freely and express their ideas around the questions. The questions were generally around three main themes. In addition we asked demographic information and also listed construction safety and health publications to determine their importance, via a Likert scale, to respondents' research.

Firstly, we assessed research and practice priorities in the respondent's country by asking the following two open-ended questions.

What are the top three construction health and safety practice issues in your country?

What are the top three construction health and safety research priorities in your country?

Secondly, we followed up on the three main findings from the Finneran and Gibb (2013) consultation report. We restated those three main findings and asked the respondent to list up to three additional topics deserving of research in each area. The language is below.

The 2013 CIB W099 Consultation Report surveyed industrialists and researchers from leading regions and identified three areas that were seen as key to moving from the current situation to the ideal OSH state.

The first was: "More responsible client behaviour – to adopt procurement approaches that support the integration of health and safety into project decision making and drive this so that it happens.

The second was “Health and safety becomes a professional responsibility of everyone in the industry. At the moment it is perceived to be the health and safety professional’s job. Health and safety professionals are generally not architects, engineers etc. They don’t make decisions. They act as advisors. The decision makers need to step up and take professional responsibility.”

The third was "Closer and more effective links between industry and academia. There is a need for a more evidence-based approach to construction health and safety. Companies need to know with certainty what works and what doesn’t. Managers are easily persuaded when there is evidence but skeptical when there is none."

We asked three questions, one for each main finding. For example, for main finding #3 we asked the question in this manner: What topics do you feel are the most deserving of priority research in the area of “Closer and more effective links between industry and academia”? Please list up to 3 topics.

For each question in this section we reiterated the definition of research priority. “Priority research” is defined as an area of research that requires priority funding and scientific interest in order to advance the construction safety and health in the coming years. When listing your topics, please be as specific and explicit as possible.

Thirdly, we asked open ended questions assessing what the future of CIB might look like. Those questions were as follows.

What other Construction Safety and Health topics are important and should be included in future analysis and discussions in preparation of a Research Roadmap? Include as many as you like. Include Health and Safety topics (ergonomics, etc.), type of construction where there might be a need (housing, etc), or general construction industry issues (small and micro organizations, etc).

What should CIB W099 be doing to better support your research and practice in construction safety and health?

Brainstorming Sessions at W099 Belfast Conference

The results of the survey were presented at the W099 conference in Belfast in September 2015 and discussed with the attendees. Attendees were broken into 6 brainstorming group with leaders assigned. Groups were assigned one of the following questions.

1. How well does education, training, and professional development prepare design professionals in the provision of inherently safe(r) designs?
2. How can the research into safety and health deliver improvements in workers conditions and their quality of life?
3. What progress towards achieving vision zero is likely to be brought about from current OHS research across all jurisdictions?

4. What are the opportunities for creativity and innovation in the delivery of safe design?
5. How can gender equality, cultural diversity and inclusivity be promoted in the design of safe(r) workplaces?
6. Are the ethical and moral challenges understood around the globe and addressed appropriately in OSH research projects?

In addition all Groups discuss these two questions:

1. Future scenario: The roadmap will unfold a vision on where we want to be in the future, e.g. in ten years' time including the stakeholders' opinions on required/envisaged future systems, processes and technologies, preferred future practices and skills etc.
2. Development strategy: What is needed in terms of knowledge, information, tools, concepts and applications to enable the respective systems, processes and technologies to develop from where we are today to where we want to be in the future?

Groups were allotted 50 minutes to discuss these questions. All discussions were audio recorded and transcribed into MS Word for analysis. Each group leader gave a report on the closing day of the conference.

4. Results and Discussion

On-line Survey

An overwhelming majority of the 48 survey respondents (39) came from academia. See Table 1. We were hoping to receive more responses from industry and government agencies. This limits the results of the survey. However, as will be noted later, stronger ties with industry and governmental agencies are important goals for W099. Table 2 shows there was a decent spread of respondents from across continents; the majority were from Europe. Noticeably absent for the survey were South American respondents. W099 has historically not had good attendance at its conferences and meetings from South America. Finneran and Gibb (2013) analysed authorship from past CIB W099 conferences and noted South America was very much underrepresented at the conferences. However, where the conference was held in Brazil in 2003 the majority of papers were from that region. One action being discussed within W099 leadership is targeting South America for a regional construction safety and health workshop or conference by 2020.

Table 1: Survey Respondents – Employment

	<i>N</i>	<i>%</i>
<i>Academic</i>	39	81.2
<i>Industry</i>	5	10.4
<i>Government</i>	2	4.2
<i>NGO</i>	2	4.2
<i>Total</i>	48	100

Table 2: Survey Respondents – Continent

	<i>N</i>	<i>%</i>
<i>Europe</i>	21	43.8
<i>Africa</i>	10	20.8
<i>Australia</i>	5	10.4
<i>Asia</i>	5	10.4
<i>North America</i>	5	10.4
<i>Missing</i>	2	4.2
<i>Total</i>	48	100

In the initial part of the survey we asked about respondent’s top three research and practices in their country. Tables 3 and 4 summarize the top findings. Safe design emerged as one of the top priorities in both questions indicating the need to better understand this concept which many believe has promise to positively affect construction worker safety and health. Work at height was the top priority for practice whereas reducing falls was important for research but not listed very high. This might indicate a gap in research to practice for reducing falls from working at height. Health related issues and small and medium organizations showed up in both lists indicating possible areas to explore.

Table 3: What are the top three construction health and safety practice issues in your country?

<i>Practice Issues</i>	<i>Number of times mentioned</i>
<i>Work at height</i>	11
<i>Safe Design</i>	9
<i>Client awareness / role</i>	7
<i>Health related hazards</i>	6
<i>Small and micro organizations</i>	6
<i>Safety culture</i>	5
<i>Motor Vehicle accidents</i>	4
<i>Language / literacy / foreign workforce</i>	4

Table 4: What are the top three construction health and safety research priorities in your country?

Research Issues	Number of times mentioned
<i>Safe Design</i>	11
<i>Cost benefit Analysis / business case for safety</i>	6
<i>Skills, competency, and training of workforce</i>	5
<i>Leadership / culture</i>	5
<i>Occupational health</i>	4
<i>More effective regulation</i>	4
<i>Better statistics, more rigorous research</i>	4
<i>Small and micro organizations</i>	3
<i>BIM potential</i>	3
<i>Supply chain</i>	3
<i>Reducing falls</i>	3
<i>Musculoskeletal disorders / human factors</i>	3

In the second part of the survey we followed up on the three main findings from the Finneran and Gibb consultation report. The first question had to do with “more responsible client behaviour”. Many comments had to do with demonstrating that safety and health does not cost more or demonstrating the cost-benefit. Some extended the thinking from green buildings which initially had the cost barrier but now eventually is viewed as cost effective. Some key comments include:

- Prove that S&H does not increase construction costs / Produce safer but also faster and with less initial costs - prefabrication?
- Money! The analogy with regards to green building can be extended further. Green buildings generally speaking cost a lot more than the alternative, if the client wants it then they pay for it as it has some intrinsic benefit to them.
- Focus on OSH prominently within the general subject of CSR. Putting it within CSR gives it a larger dimension and makes more of an impact.
- OHS is not a priority - it is pushed downstream - how to make it a priority upstream and educate developers they can be an influence.
- Learning from exemplar clients re their influence on construction H&S

The second point from the consultation report asked respondents to consider how “Health and safety becomes a professional responsibility of everyone in the industry. At the moment it is perceived to be the health and safety professional’s job. Health and safety professionals are generally not architects, engineers etc. They don’t make decisions. They act as advisors. The decision makers need to step up and take professional responsibility.” Some interesting responses questioned education and the role of the traditional OHS professional and a few are provided below.

- Broad-based multi-disciplinary H&S Undergraduate Education that ensures that all graduates understand that H&S is their responsibility.

- Research into the efficacy of health and safety professionals. Some national bodies run into tens of thousands of members. Does this contribute to a positive outcome or does it negate the ability all professionals (and employees) to exercise their responsibilities for safety and health?
- Supervisor education and OHS integration needs to be improved.
- This is a self-perpetuating myth. We all know that it is everybody's responsibility, but H&S specific professionals earn their money by trusting that very few others actually care and think they can immediately transfer risk and responsibility to the person with the title for responsibility.
- What is the paradigm of the "safety professionals" and how they are in conflict with the other professions?
- In the UK, the bold move made by the Regulators was to embed the old CDMC role in the new Principal Designer role. This should move the responsibility from the 'consultants' to the lead designer, PM or D&B Contractor. A before and after survey of this change (intervention) would be interesting.
- I agree with the statement in quotes above. I have reservations about the proliferation of OSH specialists because surely it should simply be embedded in the everyday work of managers and supervisors? More research on how OSH is actually seen by managers and supervisors would be helpful.

The third and final main point from the consultation report asked respondents to consider ideas for closer and more effective links between industry and academia. Many of the responses indicated the difficult nature of this problem. Some of the more interesting responses are highlighted below.

- There is a need for a more evidence-based approach to construction health and safety. Companies need to know with certainty what works and what doesn't. Managers are easily persuaded when there is evidence but skeptical when there is none.
- Meaningful links between academic and industry are difficult to achieve, even when both parties are keen. As a construction site manager who became an academic, I have always striven to work with the industry, but this has been challenging because academia is driven by different career determinant from industry. Perhaps we need some good research to tell us what works and what doesn't when trying to make links?
- Evidence of safety is really problematic – because it's a non-event! So perhaps a way of exploring/researching/framing this that is readily understood by practice that doesn't need stats or other traditional measures of 'impact'?
- I cannot say what deserves of priority research but how research is conducted by the universities seems all too often to be in respect of the needs of students to get a masters or PhD with little reference to the needs of the industry generally. This results in similar or even repeat research projects being carried out year after year. Maybe a priority research project is into research projects themselves to ascertain their relevance, innovativeness, dissemination and standard of research.

Respondents were asked about the importance to the following publications to their research. It was good to see the W099 conference proceedings ranked second. Table 5 summarizes those results.

Table 5: Importance of publications

<i>Publication</i>	<i>Ranked Importance</i>
<i>Safety Science</i>	4.73
<i>CIB W099 conference proceedings</i>	4.63
<i>Construction Management & Economics</i>	4.55
<i>Journal of Construction Engineering and Management</i>	4.55
<i>Engineering, Construction and Architectural Management</i>	4.18

The final two questions of the survey were open ended asking respondents what else could be done by CIB W099. The first of those questions asked “What other Construction Safety and Health topics are important and should be included in future?” There was a variety of answers including looking at organizational issues, psychological issues, nanomaterials, residential construction, and new concepts such as Safety-II. One of the most interesting responses sums it up with “Ask industry what it wants, ask the workers on site what they want, ask those who work, live and play within or on or under the things that we construct. I mean really ask, with a passion simply to eradicate work place and home death and serious health issues caused by preventable circumstances.”

The final question asked respondents to assess W099 and give advice, “What should CIB W099 be doing to better support your research and practice in construction safety?” The most popular advice centred on W099 being a venue to ensure collaboration among researchers from different countries, and engage in meaningful collaboration between conferences. Specific quotes included:

- The standard of research is inconsistent, judging from papers submitted to W099 conferences. Some are of a high standard and others are, in my opinion, barely meet degree level standards much less PhD standards.
- CIB W099 like many academic commissions/groups needs to live outside of its own membership and make a real and meaningful impact beyond the publication of its proceedings.
- More interaction between conferences.
- Try to enhance more collaboration between researchers from different countries - measure the amount of co-authored papers by researchers.
- Increase the number of developing countries' researchers at conferences. It's the same group of countries attending.
- Have a review of the proceedings of CIB W099 over the last five years and as a panel of people both academic and industrial to mark each paper for its relevancy and impact on

real life. How likely is it that lives have been directly saved or improved by the outcomes of the research?

- Organize more regional conferences.

Others were complimentary:

- I think W099 works really well! A communicative, welcoming, open and sharing group of researchers who are most willing to help and support each other. The annual conference is very good for ensuring a vibrant network, so nothing much to add here.
- Continue as you are. The aims and programme are excellent.

Brainstorming Sessions at W099 Belfast Conference

In essence it was hoped that this was a turning point conference. Each attendee has thoughts about the future of construction OHS, and now W099 must put these thoughts into action. The pre-conference debate featured four academics against four local construction industrialists examining the value and relevance of research. A Day 1 plenary session entitled “Bashing the heads of Bunny Rabbits” explained the story of the eradication of smallpox and served as an inspirational example of achieving what seemed to be an insurmountable task. Both sessions fed into the brainstorming sessions.

In this section the brainstorming sections are summarized and pertinent quotes provided. In a sense the questions provided each small working group were primer questions to get the conversations going. In the end, most sessions focused on the last 2 questions about the future scenario and development strategy. The summary of the brainstorming sessions in therefore focused on those two questions. For the sake of brevity, this section is concise.

1. Future scenario: The roadmap will unfold a vision on where we want to be in the future, e.g. in ten years’ time including the stakeholders’ opinions on required/envisaged future systems, processes and technologies, preferred future practices and skills etc. Comments around this theme include:
 - What if we changed our conference abstract instead of being an academic abstract to being a 1 page sheet it might have a figure or whatever on it but it’s aimed to be more relevant in industry and it says here is what I studied here is what is important that’s it.
 - If an industry member is going to participate they don’t write a full paper they write a one page thing that says here is my problem and any other questions I have that need to be answered in order for me to resolve the problem - an excellent little paper that academics can pick up and say let’s collaborate on this, it’s a great idea.

- Often times I don't present my best work at conference because I had submitted as a journal; I think a lot of people will just publish their B work in conferences instead of their A work and that's not good.
 - This morning (at the conference) the ILO guy mentioned action research and action research is a fantastic opportunity for collaboration between academia and research and CIB should be really leading that to.
 - With regards to diversity in construction, women tend to go into the planning and design process not out in the actually production phase.
2. Development strategy: What is needed in terms of knowledge, information, tools, concepts and applications to enable the respective systems, processes and technologies to develop from where we are today to where we want to be in the future? Comments around this theme include:
- Safe design is not just accidents but it is occupational health incidence, ergonomics, and a better work place.
 - Because we look at ethics and morals differently in different countries we can't deal with in exactly the same way all around the world.
 - I would really like to see W099 being more of a one stop shop you know the go to place for whatever health and safety issues you have. The ability to come up with resources that can give currant advice and point to work that is being done.

5. Future Directions

The results and summaries presented here are going to be further analysed and refined through a series of on-line consultative workshops to be conducted April 2015 with the goal of drafting the research roadmap around the four specific aims highlighted in Section 2. A workshop will be held at the 2016 World Building Congress for final validation of the roadmap. Reports on the roadmap will be conducted at every annual W099 meeting beginning in 2017.

6. Conclusions

This paper provides the initial insights to the development of the W099 research roadmap. It is not a complete paper with definitive conclusions as the research is preliminary. The purpose of the research roadmap is to guide the workings of CIB W099. It is not directorial and should never be considered so. The idea is that the collective experiences, expertise and research excellence of the group can be brought to bear on specific goals that will in the long run improve and enhance the safety, health and wellbeing of the communities of which we are all a part. The pre-conference academic debate and the 'Bashing the Heads of Bunny Rabbits' session considered how we as a research community can and should use creative, innovative

and fun ‘audience engaging’ approaches to deliver a serious and critical message, how do we make vision zero harm a reality? And where do each of us start on this journey? Just as the medical team (1966 to 1980) took a global and yet focussed approach to the eradication of small pox there are lessons to be learnt on how seemingly unattainable goals can be achieved with a very specific and concerted strategy, using the wide range of skills, cultural diversity and resources available within the group. For example, if we had a goal to ensure that prevention through design was to be a core element of every designers’ education within a set period, then how would we set about achieving it? It is the coming together of researchers’ approaches and specific W099 goals that will successfully deliver the strategy, as we take the research into the classroom and into the field, making it live of the page.

As researchers, individually or in groups we have the capacity to devote time to CIB W099 goals, without compromising individuality or without precluding and non-CIB W099 research projects. Setting in place a 10-year development strategy allows commission members from one conference to the next to review and update the strategy, taking into consideration the evolving world’s needs and the changing worldview. Consequently, a rolling 10-year strategy is created, which with the goodwill and endeavours of W099 will remain relevant and impactful.

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What happened when the elevator came to Norway? A case study of change in Norwegian building regulations over time.

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Abstract

This paper examines how the regulatory description of elevator technology has developed during the course of Norwegian regulation history. It tells the story of how a particular piece of interaction between a society and its built environment is described and re-described several times before it becomes a stable part of the collective horizon.

The main hypothesis underlying this paper is that the development of regulations in time reflects feedback-loops between the regulating society and the environment it builds for itself. By studying the text of the regulations, one can consequently see how the perspective of the society evolves on the subject of its built environment.

This paper establishes the built object as the pragmatic interface where society must interfere if it wants to have an actual effect on the whole of built environment. The content of society's interference becomes empirically available in imperative descriptions of the built object - found in building codes.

By carrying out a content analysis of the building codes, along two sets of parameters, we present an analysis of a specific topic in the Norwegian Planning and building Act, as well as the corresponding Technical Regulations, as they unfold in time. One parameter is the specific topic — the regulations' internal categories. The other parameter is the modal force of the normative descriptions, from recommendations via advice to explicit, quantified regulations. The reading provided by these parameters together accentuates how regulations shape the content of the built object as a societal imperative.

Visualized as a series of diagrammatic plot distributions, the analysis combines quantitative (number of plots per theme) and qualitative (modality of statement) perspectives. By adding a timeline that allows us to inspect how the regulatory situation evolves over time (from one

regulatory situation to another), we are effectively adding a reflective component to our understanding of the impact of societal values on built environment.

In addition to the exposition of the regulatory history of elevator technology, the findings present us with an analytical toolset that allows us to access and discuss the interaction between society and built environment as their reciprocity evolve over time.

Keywords: Built environment, building regulations, elevator technology, content analysis

1. Introduction

The interaction between a society and its built environment is a two-way dynamic. We embed information corresponding with our collective needs and agreement into the environment by building.

Containing explicit descriptions of the object, building codes are available sources of society's imperative actions upon the environment. This information can be studied as individual instances in time, however, when put together and regarded as process, they can be interpreted as feedback-loops – going from built environment back to society.

This study selects one specific topic, namely the description of “lifts and escalators” from the Norwegian building code and analyses its' development all the way back to the first national building law. The genealogy of “lifts and escalators”, as described in building codes, is presented along a timeline exhibiting when the topic first became a regulatory concern, how it was described, and how the description has developed over time up to present day.

The developmental pattern of the elevator description shows how even an uncontroversial building technology undergoes a development in the regulations before it finds its form. The pattern indicates relations that exist between society and elevator technology, specifically. A fundamental conviction of the authors of this paper is, however, that this pattern permits the unwrapping of more general insights into the nature of the process of regulation as an interaction between a society and its built environment.

In this specific study of Norwegian building codes, we pose the following research questions:

- What happened in the building codes when the elevator come to Norway?
- How did the regulatory description of elevators develop up to its present conditions?
- What genus of interaction does the regulatory development of elevators indicate?

In order to address these questions, firstly, the object is identified as the operative interface of interaction between a society and its built environment. The method section specifies the analytical operations done in this special case study of “lifts and escalator”-descriptions in Norwegian building codes. The findings visualise a time series of regulatory elevator descriptions into a continuous image of societal process. Finally, the findings are discussed in light of the research questions, followed by a summary with recommendations pointing towards future, comparative studies to test the hypothetical answers.

2. Theoretical Framework

Building Projects are inherently social activities (Fallan, 2008). The organisation and execution of such projects represents the collaborative effort of a community. Building projects utilise shared resources like infrastructure to enable acts of adaptation that individuals would be incapable by themselves. Regardless of being informally or formally constituted, this makes them strategic acts (de Certeau, 1980); they provide advantages to action by the manipulation of shared environment. Socially, these actions matter, not only because they are interactions, but because they contribute to ground a social reality in(to) the physical reality by their results.

The effects of a building are shared; they are beyond private interest alone. Even if the physical entity is necessary for embodying the result; a building, as shared reference, matters beyond the interest of the individual and the technology that enables its necessary scale. Buildings have (cognitive) agency in the interdependent, inherently social field of action (Gieryn, 2002). The social significance of buildings exceeds their instrumental aspects. They partake in matters of aesthetic, political and epistemological importance (Kara, 2011).

The notion of a building commonly refers to a physical artefact. To avoid the misunderstanding of reducing the basic unit of the built environment to its purely technological aspect, we refer to the base unit of the built environment with the more abstract term *object*.

It is the long-term interest of the collective that makes a society interfere directly into building projects. Settling local conflicts before they take on more large-scale consequence is a practical interest of any society that wants to remain stable over time. Any social action of the magnitude of building holds potential conflicts of interest. The broadness of its social significance and sheer longevity of a built object adds to the severity of the potential conflict scenarios. A project can be mediated by rules and regulations that solves conflict as they arise; In order to ensure its interest in the future consequences of the built object, however, a society must lay down guidelines before conflict arise — it must anticipate.

To have an actual effect on future environments, society's interest must be expressed in the interface where content is embedded into environment. It must take the form of descriptions that cannot easily be replaced or translated away among the many concerns and interest that surface within the project framework. To make a difference in the built environment, societal interest must, because it is embedded via the project process, at one juncture of translation become explicit object descriptions in order to be actionable.

The most direct imperative descriptions of the object are found in building codes. Many societal documents and institutions describe the built object, either explicitly or by implication; none, however, do it with the same specificity and imperative force as building codes. In building codes society as a collective efficiently acts upon the object; its description effectively decides whether something is built with societal recognition; building codes define what is legal. To be explicit enough to avoid the risk of mistranslation building codes actually must provide imperatives in the object scale.

Society's imperative descriptions of the built object interface represents a readily available empirical channel of the interaction between society and built environment. Building codes ideally represent a society embedding content into built environment for societal reasons. It does so in the most efficient scale and in a form that is meant to have an actual effect. The codes are well documented – their availability, impact and explicitness makes them a direct access for the analyst into the interaction between a society, as a collective, and its built environment.

Different societies have been shown to exhibit a varietal of different building regulations (Heijden, 2009). Comparative studies of building codes have been done within the EU (Meijer et al., 2002). The Norwegian code is not included in these studies. It should, however, be directly comparable, and correspondingly valuable, as a case. No studies found focus directly on building codes' explicit description of the object. The Norwegian case explicitly states a social purpose (§ 1-1, Norwegian planning and building Act). This makes it a potential reference point for studying the content a society embeds for societal reasons – that presumably are of a social nature.

Studying how a specific topic in the Norwegian building codes develops over time, provides insight into the dynamic of the interaction it represents. The effect of a building code on environment should over time have an effect (through a change in consensus among the users) back upon the regulations, urging change if the effects are not satisfactory. Modification within a particular topic of description should in theory reflect change in consensus due to a shared, collective experience. Regulation's effect on the object can be studied in a time series of building codes. By focusing on a delimited part of these time series, a material that normally remains opaque because of its density and historicity, can be laid open in the explicit way it actually effects and have effected the built environment.

Elevators exemplify a conventional building technology. They attract little controversy as a thoroughly regulated building technology. That elevators pose a significant safety risk in case of malfunction or lack of maintenance presumably contributes to this fact. A study of their development into the contemporary situation thus can shed light into the process of how a new invention becomes a conventional, regulated building technology. The manner in which the regulatory description changes would lay bare the formalist aspect of implementing technology into the environment. As the material for future comparison, this process perspective would also help us understand how building regulations play a role in making certain technologies conventional.

3. Method

Methodically, this study is conducted according to a three-part structure: Firstly, it is framed as a case study, consisting of a literary review of Norwegian regulation documents (Yin 2009). Secondly, it is internally structured as a content analysis of these documents (*Blumberg et al., 2014, Krippendorff 2013*). Thirdly, it visualises the analytical toolset that leads to the findings (*Tufte 1997, 2006*).

A content analysis enables a reading of how building regulations reflect the interaction between built environment and a society by being a method of highlighting how it makes its content (description) explicit. The goal of a content analysis, according to Krippendorf (2013), is to “infer features of a non-manifest context from features of a manifest text”. In this study, these telling features are made apparent by displaying an inventory, not only of what (about the object) the building code describes, but also how it describes: How it reflects its purpose, and effects as a societal imperative.

A selective reading of a time series of Norwegian building codes generates the input of this study. Regulatory statements with descriptive reference to the built object demarcate the units of analysis. The object of reference corresponds with the output of a normal normal building project as defined in professional standards (Moe; et al., 2010). This is a delimiting choice made to focus on built regularities rather than exceptions.

Regulation documents covering the top level of building code, specifically, building Acts and technical regulation are the source texts of this content analysis. Every regulatory situation in the history of the Norwegian building code, as defined by the valid Act and its technical regulations, provide a series of descriptions. This corresponds with the acts of 1924, 1965, 1985, 2008, and the technical regulations of 1928, 1949, 1969, 1985, 1997 and 2010. In addition, a substantial supplementary document expanding on fire safety in institutions from 1963 is included. Yearly revisions of the regulations texts are not included in this study. The sources are limited to the mentioned documents with their revisions as they were openly available at lovdata.no, the Norwegian data base of legal material, per October 2015.

The Norwegian building code handily categorizes its description of the built object into topics. Applying topic as an analytic parameter creates a selective reading into the “Lifts and escalators” topic (section 29-9, chapter 29, Act 2008), as all other topics effectively fall outside our analytical frame.

The regulatory descriptions designate different degrees of explicitness to different components of its description. This scale emerges from the linguistic modality a statement is expressed in. Within the language of the building code, a relative degree of explicitness forms a hierarchy that remains opaque in normal reading. These structural “how”-components of the regulatory description actually affect the real world pragmatics of what is built.

By assigning each analysed statement with a linguistic modal degree, the analytical construct recodes the reading of the regulation to show a relative relation between each statement. This enables a reading of the building code that accentuates the modal aspect. The scale of modal degrees is derived from the actual, present Norwegian Planning and Building Act (2008). As a continuity, legal modalities expresses an interval spanning from vague possibility to singular, unambiguous necessity. In the Norwegian case this correspond roughly with four levels: From making *Recommendations*, it increases to *Cohesive recommendations*, before becoming binary (yes, no) as *Absolute regulations*, all the way up to the most forcefully specific: *Quantified regulations*. This most specific tier describes legal necessity by prescribing intervals (within,

below or above) of certain pre-established values to which the built object must correspond to be legal.

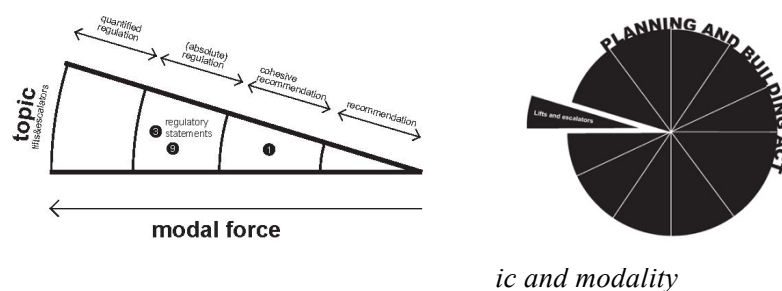
This analytic reading of a specific topic of description in Norwegian building codes accentuates “how” a topic is expressed. Accentuating the workings of a modal hierarchy within the regulation text reveals the mechanics of (regulatory) expression that corresponds with the pragmatic effect of the building code on built reality. By adding a timeline, the development of descriptive force and explicitness of the topic in question appears.

Because of the imperative signification of the building code, high legal linguistic modality corresponds with forcefulness of the actual effect it prescribes to built reality. Revealing descriptive force unlocks a perspective on the building code’s actual effects. This should correspond with a society’s will to enforce this specific solution out of societal interest in its effect on the built environment. Topic in itself merely designates societal interest, and topic volume only society’s interest’s relevance for settling controversy.

Reference numbers assigned to each unit of analysis ensures replicability to the study. Any individual number can be traced back to a statement in the regulation texts. This makes the procedure replicable and testable. The process relies on human judgment interpreting a grammatical/semantic material. It would not be suitable to an automated procedure. The reliability of the study could be developed in the future, by multiplying the procedure, either to provide Bayesian reliability, or a quantified deviation measurement.

4. Analytic Procedure leading to Findings

Firstly, the body of each regulation text is sorted into topics using the 2008 chapter and sections headlines. The “Lifts and escalators” topic is selected for a specific, in-depth study (Figure 1). Secondly, each individual statement describing the topic is given a number and allotted with a modality according to the scale (also Figure 1).



Thirdly, repeating this to all the 11 unique regulatory situations in Norwegian history since 1924 leaves us with a collection of comparable diagrams showing volume and modality of “lifts and escalators”- descriptions (Figure 2).

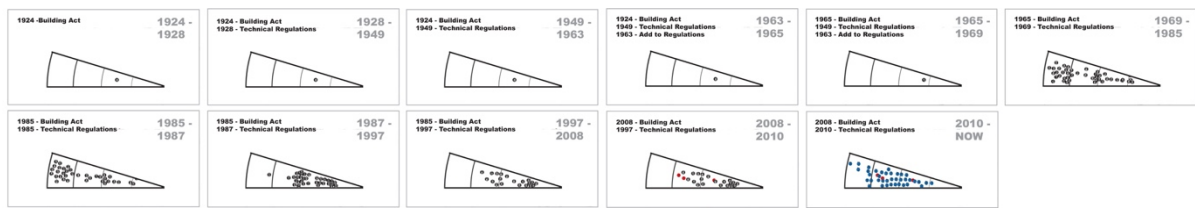


Figure 2: The 11 unique regulatory situations of Norwegian history

Fourthly, the diagrams are distributed chronologically, allowing us to read them as a process. Fifthly, we add a time-line of 100 years and distribute the diagrams on that timeline showing the Norwegian history of elevator regulation. Sixthly, removing the individual diagram, leaving only the plots, the y-axis of the combined diagram now denotes modality, roughly corresponding with descriptive specificity and force (Figure 3). Seventh, and finally, we approximate the plots to a graph by visual analysis; this leaves us with an historical image of the specificity of elevator regulation in Norway (descriptive modality force / time) as our findings.

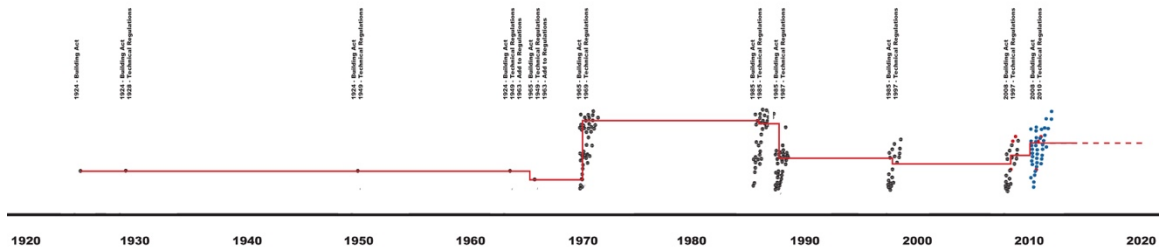


Figure 3: Adapting a graph to the scatter plot

5. Findings

According to the graph in Figure 3, “lifts and escalators” went from barely regulated to very specifically so in 1969. Assuming this occasion corresponds with the period elevators became a proper regulatory concern, that is; a regular building technology and not just a possibility, the introduction of societal interest is characterized by a dramatic increase in modal force (will to specify). At this introduction, the regulation of elevators in built environment appears distinctly specific and forceful.

In 1969, elevator specificity went from barely described to very concerned. The development of regulatory description, however, is characterized by a decline in specificity during the 1980s, that continues in 1997, before a new and uplift in specificity (modal force and volume) appears in the present building code. This new top, however, peaks at a lower level than the peak of specificity characterizing the introduction of the topic into the Regulatory body in the 1960s.

Doing an $F'(x)$ operation on the function (Figure 4), now displaying the finding as degree of

modal change/time, displays this tendency even clearer. There appears to be a significant positive change in modality/specificity of description in 1969, followed by negative tendencies in the 80s and 90s, and a new, less dramatic positive tendency leading into the present situation.

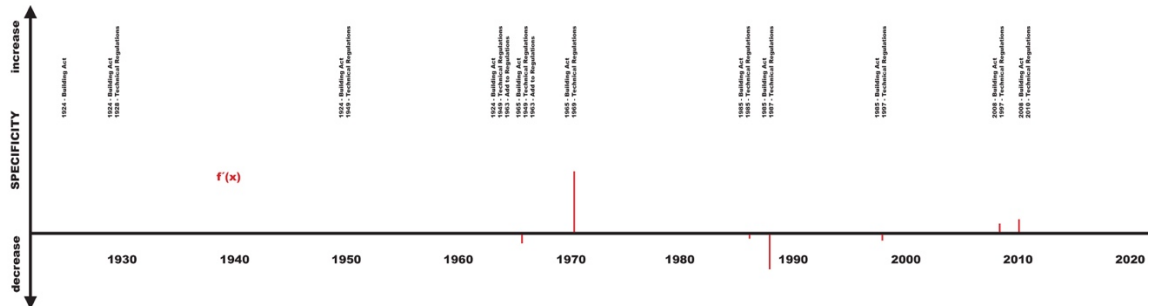


Figure 4: Modal changes in elevator regulations

6. Discussion

The findings clearly indicate that elevators were introduced as a regulatory concern which significant modal force, corresponding with a high degree of specific effects in the built environment. The difference between merely being regulated—a requirement that elevators must be accepted and inspected by officials (the Act of 1924)—to being described in details by the regulation text—down to the diameter of the metal cord used in the mesh in the bottom of the elevator shaft—is quite dramatic.

The modalities of the introductory 1969 technical regulations indicate that strong societal forces took very specific interest in the elevators. Since elevators were relatively new to the general public, whom the building code represent, this force may be the result of either an expert’s perspectives, or that the safety concern (or phobia) connected to the novelty of elevators lead us, as a collective, to limit them to one specific form.

After the initial specificity, our findings show that the regulatory description went through some adjustments, clearly becoming less forceful (and specific), first in 1987 and further in 1997, before they have a resurgence of specificity in 2010. They are yet, however, to reach the same level of force and specificity as the introductory situation of 1969.

The fall in the 80s and 90s, and the new, albeit lower peak in 2010, clearly suggest that the development does not follow a linear pattern. The pattern of the regulatory description of “lifts and escalators” in the Norwegian building code that follows from 1969 is neither a gradual increase in specificity, nor a decrease. According to the findings, elevator regulations rather exhibit a wave-like development. From the present perspective in this historical process, descriptions swing from a high initial state towards a lower overall degree of specificity: From

few accepted elevator solutions to several, yet far from laissez-faire.

If this pattern corresponds with an interaction between the regulating society and its built environment, it seems to be characterised by an action-reaction process. A society that embeds content into the built environment by imperative should be expected to adjust these imperatives over time: As a collective, society learns from the consequences of its imperatives through their effects, working back upon its originators from the built environment. The wave-like pattern displayed, if it does represent this interaction of action-reaction, could correspond with a learning process.

Looking at the tendency at display from 1969 and through the present situation, based on the hypothesis that the underlying dynamic driving this development is a learning process, then it seems reasonable to suggest that the descriptions of built environment nested in building regulations, and in this specific case of building technology that is elevators, behave very much like some sort of a collective inquiry. In fact, the Norwegian society poses a very specific hypothesis of the correct (societal) specification of elevators in the built environment in 1969. The collective learns from the consequences of this description, re-state new, less constricting hypothesis in the 80s and 90s, learns from these, and (finally) finds that we need to be more specific in 2010, however not as specific as the first try in 1969 (illustrated by line drawn between peaks in $f(x)$ in Figure 5 below).

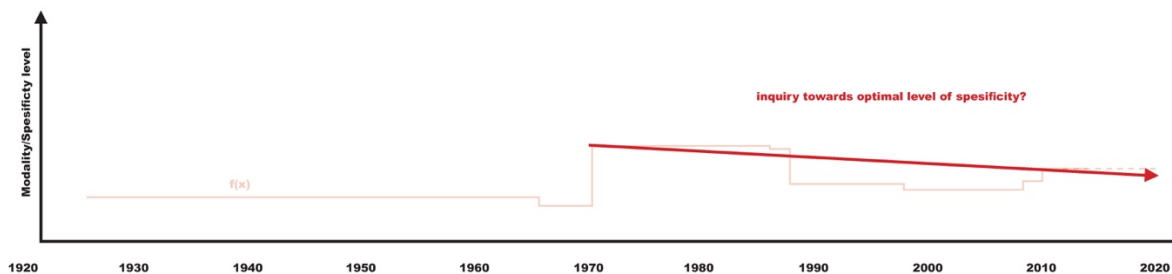


Figure 5: The historical development of Norwegian elevator regulations

If the development of “lifts and escalators” in the Norwegian building code represents a general pattern, the interaction between society and built environment evolves like a big collective experiment. Based in shared interest, Norwegians experiment (try and retry) with the correct level of specification; that is, a beneficiary balance between limits and possibilities of a building technology to meet our collective needs and aspirations; as a society being a temporal continuity. This implies that “the first” description, like the specificity of “lifts and escalator”-regulation in the 1969 is likely to be less than optimal. As a part of a learning process, however, this is just a part of the process. It is adjustment through learning from consequences over time that represents intelligent improvement (and not hitting the spot the first time by share luck).

Learning is not an unlikely explanation of the observed dynamic as it represents a driving force in itself, for intelligent creatures and societies. Learning characterizes the enjoyable process of improvement. Improvement of building codes over time, by collective inquiry is subsequently the collectively enjoyable process towards the most stabilizing, yet dynamic balance of technological augmentation of our environment.

7. Conclusions

This study displays some tendencies in the introduction and development of elevator description in Norwegian building codes over the past 100 years. The main tendency shown resembles a wave-like development from high to lower specificity – a development that as a manifestation of an interaction between a society and its built environment, seems to correspond with that of a collective learning process.

The scientific contribution of the findings and the toolset developed represents an analytical perspective on the dynamic between society and built environment. This perspective could be of methodical value for regulation professionals, policy makers and technologist alike. It also, however, opens the question of whether these observations of the elevators regulation history are unique to Norway. Few comparative studies cover both the EU and Norway, and for the findings of this study to be generalizable, further studies are in order.

By replicating the analysis to cover building technologies besides elevators, in and outside the Norwegian regulatory situation, the perspective and hypothesis suggested can be tested to see whether “lifts and escalators” regulation represents an oddity or if it embodies a more general pattern in the relationship between society and built environment – that of a reciprocity characterized by continuous inquiry: Of testing, adjusting and improving.

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Spatial Meteorological Information for Built Environment in the Changing Climate of Finland

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Abstract

Climate change will decrease the heating and increase the cooling energy demand of buildings, and poses challenges in urban planning and construction of buildings. On the other hand, buildings also affect the local climatic conditions. The complex interactions between climate and built environment need to be taken into account in urban planning, designing new buildings, as well as, in renovation of existing buildings.

Two types of past and future hourly test reference weather data sets have been produced for selected locations in Finland, one for considerations of energy demand and the other for purposes of building physics. Using the data sets as input for dynamic building energy simulations, the annual energy demand for heating and ventilation in southern Finland was assessed to decrease by 15-18 % by 2050, and the annual cooling energy demand to increase by 28-34%. Spatial distributions of the future changes in heating (HDD) and cooling (CDD) degree days over the whole country were assessed based on gridded (10 km x 10 km) daily temperature data. By the end of the century in a high emission scenario the HDD will reduce by 1000-2000 Kd compared to the present climate. In a low emission scenario the HDD will be reduced by 500-1000 Kd. The biggest changes will take place in northern Finland and during winter months. The heating period will be shortened by several weeks. The cooling energy demand will remain small compared to heating demand also at the end of the century.

However, these assessments based on meteorological measurements at standard weather stations do not give adequate information about climatic conditions in urban areas. An urban heat island study and simulations with an advanced high-resolution weather model demonstrate how built environment can modify the spatial temperature distribution in Helsinki. Besides affecting the building energy demand, the urban heat island effect intensifies adverse impacts of heat waves on human health. Buildings should be thermally comfortable not only in weather conditions typical for the present-day climate, but also in extreme weather situations and the changing future climate. Comprehensive, integrated information is needed to assess well-being in built environment.

Keywords: heating and cooling demand, climate change, urban heat island, health impacts, weather models

1. Introduction

Ongoing climate change, as well as, climate change mitigation and adaptation policies will have remarkable impacts on built environments. In cold climatic conditions like in Finland, the energy efficiency and reduction of greenhouse gas emissions are main climate related concerns. However, warmer, wetter climate and side-effects of improved insulation of buildings may also have adverse impacts on wellbeing of people, besides increasing the cooling energy demand in summer. Moisture control appears to be challenging in newer buildings both during construction and in use, and mechanical ventilation requires also energy. On the other hand, buildings and changes in land use affect local climatic conditions. Therefore the complex interactions between climate and built environment need to be better understood and utilized in urban planning, and assessed together with sociodemographic changes in order to provide healthy and comfortable built environment for people. Urbanization and socio-demographic changes, like an increasing share of elderly in the population, will further emphasize the importance of integrated, detailed spatial assessments.

Here we mainly concentrate on spatial meteorological information for built environment in the changing climate of Finland. Examples are given about estimates of future changes in the heating and cooling energy demand of buildings in Finland due to climate change: Besides temperature, we briefly describe here changes in other meteorological parameters relevant for built environment such as humidity, precipitation, wind and solar radiation. Furthermore, we demonstrate the urban heat island effect and impacts of built environment on weather and climate in a metropolitan area in Finland. Heat related mortality and regional differences in vulnerability of Finnish population during heat waves are discussed in context to demonstrate the need for integrated information from various sources to be used in urban planning, construction of new buildings as well as renovation of old houses.

In chapter 2 we shortly describe both present and future climate in Finland in general, proceed next to the tailored climate scenarios for building in form of test reference weather data sets and spatial calculations for changes in heating and cooling degree days. In chapter 3 we concentrate on impacts of buildings to the local weather and climatic conditions and in Discussion we reflect on use of applications of these information e.g. in planning green areas in urban areas and preparedness during heat waves.

2. Buildings in changing climate

2.1 Climate variability and change in Finland

The climate of Finland is influenced by the northern geographical position of the country and its location in the western coastal zone of the Eurasian continent. Weather types may vary rapidly depending on the direction of the airstream, and the seasonal and inter-annual climate variabilities are large. Due to cold climatic conditions the energy demand for heating dominates over cooling in Finland. However, the energy demand for cooling cannot be ignored in a warming climate.

The annual mean temperature has already increased over 2 °C since pre-industrialized time in Finland, implying a rising trend of 0.14 °C/decade (Mikkonen et al, 2015). The warming has been more rapid since the 1960s. The observed increasing trend has been higher during winter than summer. The temperature increase exceeds the global average in high latitude countries like Finland. The aim of international climate politics to limit the increase of global mean temperature to 2 °C would mean that the annual mean temperature in Finland would increase by almost 4 °C and precipitation by 10-15 %. In case of high greenhouse gas emissions the annual mean temperature would increase about 6 °C by the end of the century and annual precipitation about 20 % by the end of the century.

The increase in summer temperatures is also expected to manifest itself in longer and more intense heat waves in the future. Based on Ruosteenoja et al. (2013a), summer days with a daily mean temperature above 20°C may occur at the end of the century three to four times as often as during the recent decades. Similar increases are expected for the duration of hot periods.

Along with increasing temperatures, Finnish winters are becoming moister, darker and less snowy. Solar radiation in winter is estimated to decrease by 10-15 %, relative humidity to increase by 2-3 percentage units, and in southern Finland the snow water equivalent will probably be reduced by 70-80 % (Ruosteenoja et al. 2013a). In winter the probability of precipitation in form of rain or sleet will increase, and risks related freeze-thaw damages alter. These changes are thoroughly discussed in the works of Ruosteenoja et al. (2013b) and Vinha et al. (2013).

2.2 Test reference weather data sets

Two types of test reference weather datasets have been developed for Finland, one for considerations of building energy demand and the other for building physics. The former data set aims to describe typical meteorological conditions and the latter critical conditions from the viewpoint of damages in buildings due to moisture.

The impacts of climate change on the demand, delivered consumption and costs of building energy have been assessed by Jylhä et al. (2015) for a typical residential house in Finland. The influences of air temperature, solar radiation, wind speed and air humidity on energy demand were simulated by the IDA Indoor Climate and Energy simulation program, utilizing a recently-developed synthetic Test Reference Year (TRY) hourly weather data as its input (Kalamees et al. 2012). The TRY2012 data set, describing typical climatic conditions in 1980-2009, appeared to work well in capturing the average building energy demand of the example house during that 30-year period. Future TRY data sets were constructed by modifying the TRY2012 time series in accordance with climate model simulations.

Using these future climate projections as input for the building energy simulations, it was assessed that the annual energy demand for heating of spaces and ventilation will decrease by 15-18 % by 2050, whereas the annual cooling energy demand will increase by 28-34%, the lower and upper ends corresponding to the multi-model mean climatic responses to low and

high greenhouse gas emission scenarios, respectively. The impacts of the changing climate on the delivered energy consumption and energy cost per m² were assessed using three alternative heating systems and two different cooling systems. With other influential factors (e.g., building technology and practices, floor area) held constant, climate change is expected to reduce the amount and cost of energy used in buildings in Finland. The findings can be used to identify potential needs to revise building codes and to improve the energy performance of buildings in order to better mitigate climate change and adapt to its impacts. The results also demonstrate the added value of dynamic building energy simulations compared to the use of cooling degree-days.

The Finnish climate is rather demanding for building physics. Weather datasets containing temperature, relative humidity, wind speed and direction, direct and diffuse solar radiation and precipitation at hourly resolution in 1980-2009 have been produced by Ruosteenoja et al. (2013b) for four locations in Finland. On the basis of the 30-year datasets, two building physics test reference years were selected by Vinha et al. (2013) to represent weather conditions that are particularly critical for the emergence of damages due to moisture in buildings. Corresponding future scenario test reference weather datasets for the building physics purposes were then constructed by employing special treatment for the solar radiation and precipitation data. According to Vinha et al. (2013), climate change increases risks related to moisture behaviour and fault tolerance in several present-day envelope structures.

2.3 Heating and cooling degree days as spatial information

In order to provide spatial information about the anticipated impacts of climate change on heating and cooling demand, use was made of recent past and projected future temperature data on a 10 km x 10 km grid over Finland (Pirinen et al, 2014). The baseline values for the heating (HDD) and cooling degree days (CDD) in the present climate were calculated for the 30-year climatic normal period of 1981-2010, and future scenarios for three 30-year periods (2010-2039, 2040-2069, 2070-2099) were produced for three greenhouse gas emission scenarios (SRES A2, A1B, B1). In operational monitoring of heating demand, an indoor temperature of 17 °C is used in Finland as the base temperature for heating degree day calculations (S17), and was therefore also applied here. For cooling degree calculations, +18 °C was chosen as base temperature. Currently in Finland the cooling demand is not monitored operationally.

In the present climate the HDD varies from 3800 Kd in southwestern Finland to 5000-6000 Kd in northern Finland, and heating demand is the highest typically in January. The biggest changes due to climate change are projected to take place in Lapland, where the HDD will be more than 1000 Kd smaller already by middle of the century in the high emission scenario. By the end of the century the heating degree days will be reduced by about 2000 Kd in northern Finland and in southern Finland by more than 1000 Kd (Fig 1, left) in high emission scenario, the reduction is about one third of the value in present climate. In the low emission scenario the heating degree days will be reduced by 500 in southern and 1000 Kd in northern Finland.

Thus, Finland will benefit of climate change through reduced heating energy demand. The changes will take place throughout the heating period and are the biggest in the middle of the winter when measured as absolute values. However, changes in May and September will also be large due to the changes in the length of heating period. In the present climate in southern Finland the length of heating period is about 250 days (8.5 months) and about 300 days (10 months) in northern Finland. By middle of the century the heating period will already be a couple of weeks shorter in southern part and about one month shorter in northern part of the country in case of the high emission scenario (A2). By the end of the century in northern Finland the heating period will be about 1.5 months shorter and in southern Finland 3-4 weeks shorter than in present climate (Fig 1, right).

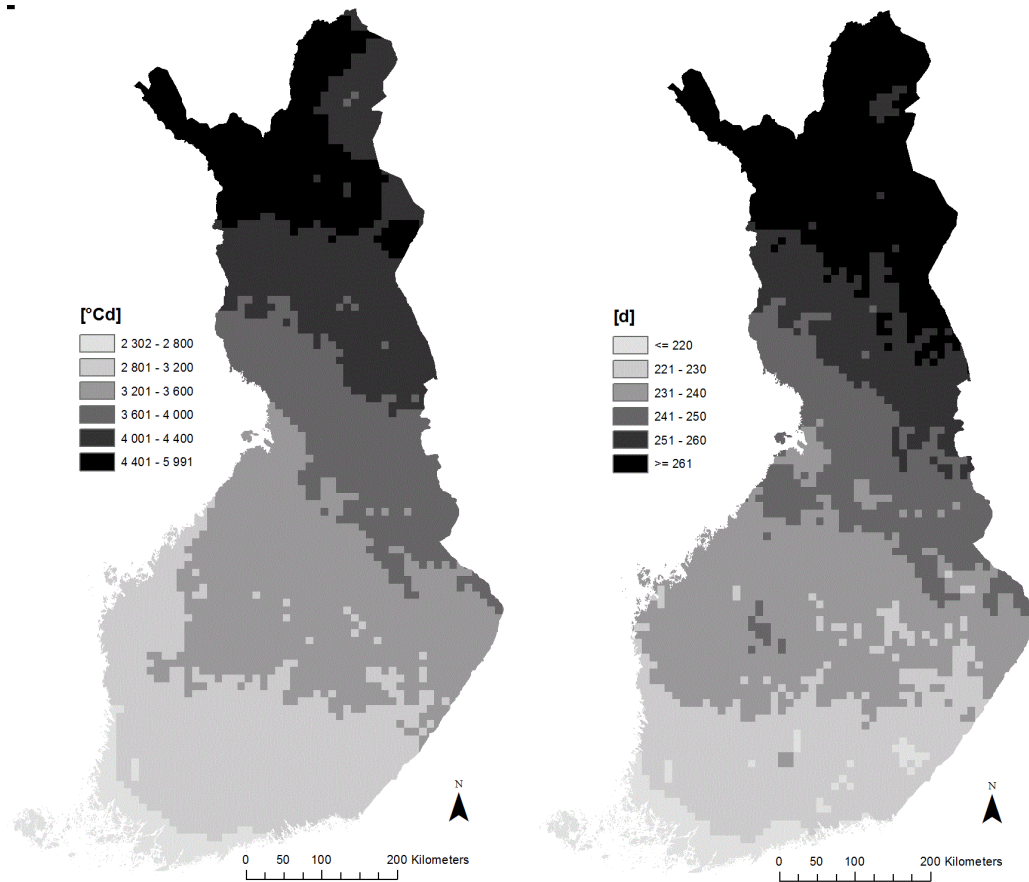


Fig 1. Heating degree days (left) and length of heating period (right) in Finland at the end of the century in high greenhouse gas emission scenario (A2) (Pirinen et al. 2014).

As discussed by Jylhä et al. (2015), the simple CCD method seems to work less adequately for quantitative estimates of future changes in energy demand than HDD does. This is because solar radiation notably affects cooling energy demand in Finland. In qualitative terms, however, CDD can be a useful measure in approximating the spatial distribution of future increases in cooling energy demand, provided that future changes in Finland will be spatially more uniform for solar radiation than for temperature. Obviously, more research is needed for quantitative assessments of future increases in cooling energy demand.

3. Built environment changes climate

3.1 Urban heat island in metropolitan area in Finland

By the end of the decade 2000-2010 the urbanization rate in Finland reached 85%, which means that a little bit more than 4.660.000 Finns live nowadays in cities or city-like settlements. Since the urban heat island effect was recognized in London in the beginning of the 18th century, uncountable numbers of researches (Arnfeld, 2003) have shown that cities and city-like settlements change the climate inside their borders. In general this phenomenon is based on the facts that surface areas absorbing direct solar radiation are greater in cities than in the non-build-up surroundings, while evaporation by trees, bushes and other green areas and sealed surfaces is weaker. Furthermore it is known that every agglomeration of buildings is producing their own heat island effect, at least in some extent. This is also valid for Helsinki where, beside the downtown city centre on the peninsula in the Gulf of Finland, several local centres, like Herttoniemi and Malmi, show their unique urban heat island effect (Fig. 2, Drebs, 2011). Maximum detected air temperature differences between the city centre and surrounding rural area in Helsinki, approximately 9 degree Celsius (Drebs and Vajda, 2006), are in concord with other researches, where the number of city inhabitants has been correlated with the greatest urban heat island intensity (Oke, 1973).

In the changing climate the human well-being in cities will arise as an important concern for inhabitants, city planners and decision-makers. Due to demographic changes, and temperatures differences in urban areas, questions on how to handle the changes in cooling and heating energy demand will become more actual. In order to mitigate adverse impacts of urban heat island, green infrastructure (green roof, green walls, allotment garden, parks, avenues) and natural ventilation corridors need to be considered in city planning.

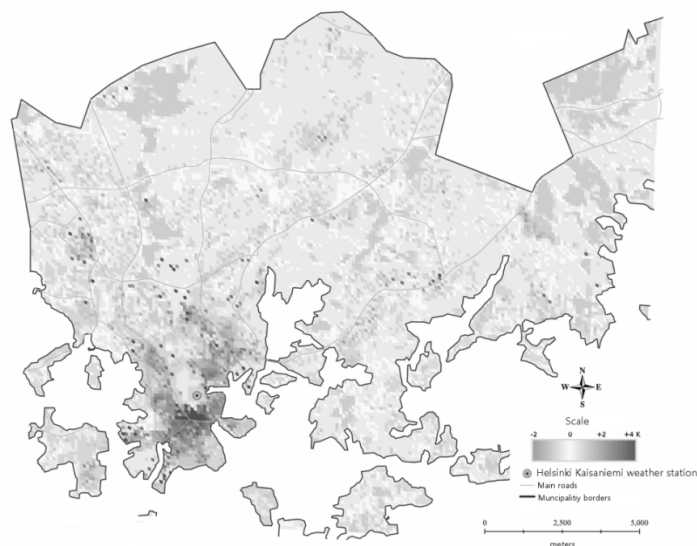


Fig. 2. Average temperature differences in Helsinki compared to Helsinki-Kaisaniemi weather station during the one year period July 2009-June 2010. (Drebs, 2011)

3.2 Physically-based modelling of the urban effects

In assessing the impacts of global climate change in an urban landscape, a challenge is presented by the fact that climate model output data have a coarse temporal and spatial resolution. Besides, observed weather data representing the present climate conditions do not account for differences between the actual climate in cities and at weather stations that are typically located in open vegetated land (rural or natural landscapes). High-resolution physically-based land surface models, by contrast, account for local characteristics when simulating the exchange of heat, water vapour, and momentum between the atmosphere and the underlying surfaces, as well as the meteorological conditions close to the surface. Examples of the detail added by a land surface model are given in Fig. 3, showing simulations carried by coupling the SURFEX land surface model (Masson et al, 2013) to operational forecasts of the Finnish Meteorological Institute. Surface characteristics including land use, vegetation types, and urban morphology were given on a grid of 500 m by 500 m.

The upper two panels of Fig. 3 show the temperature in the afternoon on a warm and sunny summer's day. The temperature above the roof-top level, shown to the left, is a 36-hour forecast by the operational HARMONIE system, based on the AROME atmosphere model (Seity, 2011), here applied on a 2.5 by 2.5 km grid. The spatial pattern is in this case entirely dominated by the land-sea contrast. This contrast is prominent also closer to the ground and in the street canyons (SURFEX: upper left), but there is additional spatial variability, which can be related to the surface characteristics (not shown): the warm (dark) spots are found over densely built areas where the cooling effect of evaporating moisture is small, while fields, forests, and water bodies are relatively cool.

The lower two panels of Fig. 3 show corresponding data for a cold winter's day. Above the roof tops (left), the pattern is again dominated by the land-sea contrast, but with opposite sign compared to the summer case: the ice-free sea is now warmer than the land. As in summer, the land sea contrast is prominent also near the ground (right), and, as in summer, the land use and surface characteristics again give rise to additional spatial variability. Dense urban areas are again relatively warm, owing now mainly to the heat released from buildings and traffic (urban heat island, see Sec. 3.1) while forests and field remain colder.

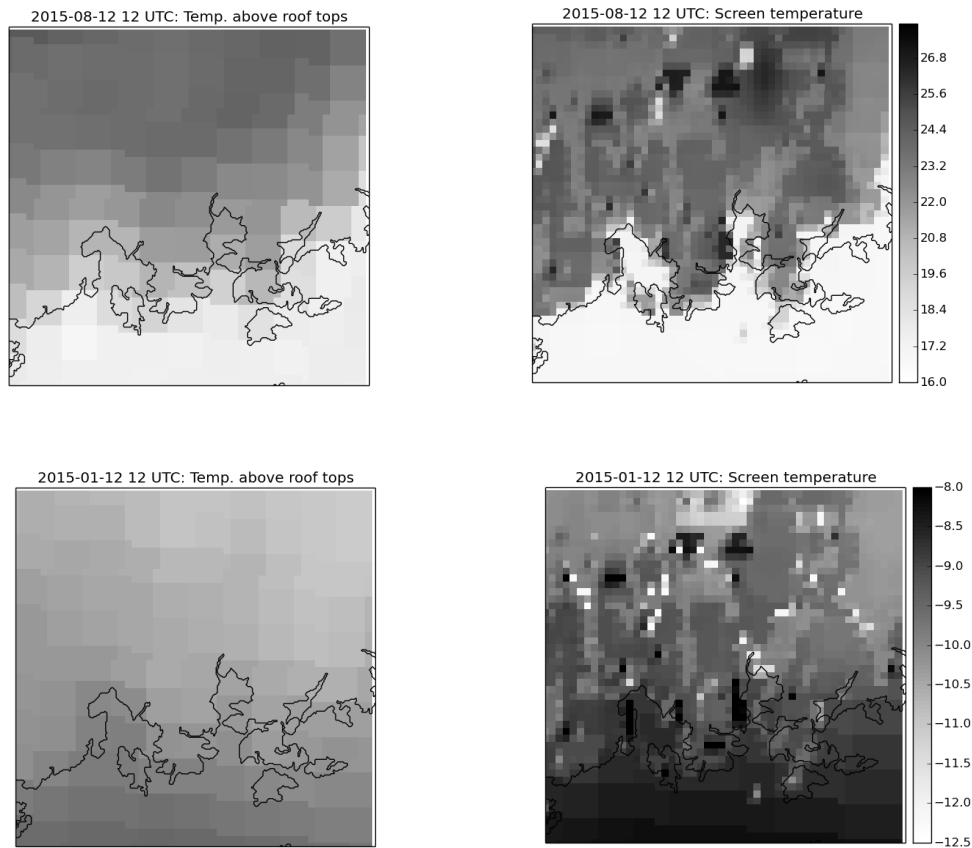


Fig. 3. Examples of the influence of a built-up environment on temperature in summer and in winter. The upper panes show the temperature (degrees Celsius) around the Helsinki region at 12 UTC on the 12th of August 2015. Left hand side: operational 36-hour forecast above the roof top level, right hand side: SURFEX model at screen level. Lower panels: as the upper ones, for 12 JTC on the 12th of January 2015.

4. Discussion

The energy efficiency of the buildings and the climate policy have been the main motivation for the heating and cooling energy projections and their spatial assessments presented here. However, use of the climate information could be further extended for the benefit of sustainable development and quality of life of habitants in urban areas. Climate data, socio-demographic and building stock data can be compiled and studied in more comprehensive way than often currently done. Such comprehensive considerations should be taken into account both in renovation of old building stock and in planning and construction of new urban areas and buildings.

Most of Finland is sparsely populated and, thus, most of both heating and cooling energy is actually needed in southern Finland. For monitoring the development of energy efficiency in Finland, and reporting heating demand of buildings to EU-level with one figure only, we also

calculate annual average HDD which is weighted according to the population distribution over Finland. More accurate energy demand assessments might be obtained by combining spatial weather and climate information with the detailed building stock information and population distribution and their future scenarios.

In spatial planning it is important to recognize areas with vulnerable population groups and functions like nursing facilities during extreme weather conditions. Vulnerability to temperature extremes varies depending on socio-economic and demographic distribution and changes in them, e.g. on the proportion of elderly in the population. During the heat waves 2010 and 2014 in Finland about 300 extra deaths took place. According to Kollanus and Lanki (2014) the impact of hot weather can be seen in causes of deaths due to cardiovascular and respiratory diseases, mental disorders and nervous system diseases among elderly. In that study nursing facilities especially were found to have increased mortality during heat waves.

We demonstrated the urban heat island effect in the present climate of Helsinki. As a following step, it would be important to make multi-disciplinary studies to provide information on spatial distribution of population vulnerability (age distribution, housing) to temperature extremes in urban areas. Good examples of such studies are made e.g. in London and Hamburg (Wolf and McGregor, 2013; Schoetter et al., 2013). Recognition of vulnerable areas within the biggest cities in Finland could be utilized not only by urban planners but also by other authorities such as health and rescue authorities, and security of supply.

Furthermore we demonstrated using weather models how buildings can impact the local climate. These kinds of assessments could be utilized in planning of new areas. The efficiency of green infrastructure in minimizing the negative impacts of urban heat island can be studied with the help of such a model. The intensity and extent of the heat island vary according the weather patterns. The weather prediction models are continuously improving both in spatial and time scales and future weather service may be able to provide more detailed forecasts for daily technical building services.

Due to the Finnish long heating period, the security of energy supply is important in all weather conditions, especially in rural areas. We have good experiences on the use of weather forecasts in early warning systems in many sectors of society related to power cuts due to wind storms. The utilization of weather forecasts could be improved in preparedness and early warning systems also in cases of heat and cold waves, especially in health sector.

5. Conclusions

Impacts of climate change and complex interactions between climate and built environment need to be taken into account in decision making in urban planning, designing new buildings and in renovation of existing buildings.

Nowadays, climate information is mainly used in assessments of energy demand in buildings, and energy efficiency is a driving force in design of new buildings and renovation of old ones. Besides energy considerations, however, it would be important to assess combined impacts of climate and built environment on the health and well-being of people, as well, and thus improve the quality of life.

In the future the present work can hopefully be extended into systematic inclusion of weather and climate information in urban planning e.g. in multicriteria analysis for decision making in order to compare various alternative plans (Martinelli et al., 2015). Microclimatic simulations in residential area would help in providing healthy and thermally comfortable environment for inhabitants with best possible use of green infrastructure, and distribution of open spaces and buildings both in present and future climate.

Higher resolution spatial weather and climate information together with vulnerability assessments of population in built environment could also be used in preparedness during heat and cold waves. The preparedness would realize as prevention of extra health problems and burden in health care systems. Daily technical building services would benefit from new, improved weather forecasts concepts that are tailored especially for their area of the interest.

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Application of Transient Hygrothermal Modelling to Assess Thermal Transmittance: A Case Study in Dublin, Ireland

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Abstract

Building performance simulation has an important role to play in accurate energy efficient design, yet it is widely recognized that over-simplification in the modelling of physical phenomena leads to substantial sources of error. The evaluation of building envelope thermal performance is fundamental to the correct design of energy efficient retrofit solutions. Thermal transmittance (U -value) is a widely used and standard calculation method to assess thermal performance of the building envelope. However, simple calculations such as these do not incorporate climatic conditions applicable to the locality of the building. Simple simulations can be composed to account for moisture loading, moisture retention and the direct result of local climate conditions on transient thermal flux and thermal transmittance. This paper presents selected results of a recently completed research project to demonstrate that it is possible to assess moisture content to simulate corrected transient thermal transmittance of external walls using a hygrothermal modelling tool. The hygrothermal responses of cavity walls in a 1970's elderly nursing home in Dublin, Ireland and its components were assessed with a water content chart, linked to the moisture dependent conductivity of materials. The results and discussion presented in this paper highlight a need for the application of hygrothermal simulation tool to design optimum thermal retrofit/upgrade of exterior wall systems in various geographic locations.

Keywords: Existing building, Retrofit; Transient thermal transmittance; hygrothermal modelling; Performance gap

1. Introduction

In the last decade the obligation to ‘retrofit’ existing buildings in response to the long-term challenges of climate change and resource constraints has gained increasing significance (Dawson, 2007, Kelly, 2009, Centre for Low Carbon Futures, 2011, May and Rye, 2012). In the last couple of years the EU Directive on the Energy Performance of Buildings (EPBD) was superseded by the Recast EPBD placing a further emphasis on even higher thermal performance and efficiency levels of existing buildings in Ireland. This emphasis has been reinforced by the publication of the new Technical Guidance Document (TGD) Part L 2011 enforcing higher fabric efficiency values on existing buildings. Despite this, Ireland’s greenhouse gas (GHG) emissions including CO₂ are above the European (EU27) average and still rising to levels that will exceed allowances and commitments made for the Kyoto Protocol (Agency, 2015a, Agency, 2015b). Delivering a sustainable retrofitted building project remains a challenge in the industry due to lack of managing knowledge in sustainable construction projects. It has been argued that there is a possibility for substantial carbon emission reduction through appropriate approaches to sustainable retrofit, however, achieving it presents a multifaceted and difficult problem to the industry due to lack of knowledge management (Shelbourn et al., 2006). As 70% of current residential housing being built pre-dating building regulations including extremely poor insulation and energy efficiency levels, energy consumption optimisation and CO₂ emission reduction can be applied through the thermal upgrade of existing buildings to target the highest savings (Kema, 2008, Shelbourn et al., 2006).

Current research recommends further research on the thermal properties of traditional building materials and construction components; improvements to the thermal transmittance calculations; and a standardised methodology for in-situ measurement of thermal transmittance (Baker, 2011, Künzle, 1998, Little, 2011). Correspondingly, Alliance, (2012) noted that there is little work which describes or quantifies the performance of buildings in relation to energy efficiency while the evidence available is often flawed as it is not based on direct measurement or observation of buildings prior to retrofit work and frequently relies on modelled assessments to prove assertions of improvement.’ It is hoped that this research will inform the on-going deliberation and impact thinking with reference to the measures undertaken to reduce carbon emissions in relation to existing buildings.

The following paper details research into the thermal and hygrothermal performance of an existing residential nursing home in Dublin, Ireland. The nursing home is a 1970’s cavity wall with brick veneer façade, due to be retrofitted in both layout and thermally. A number of solutions were presented for thermal upgrade, with hygrothermal simulation applied to each. The existing building was then analysed using thermography in accordance with ISO 6781:1983.

The research set out to evaluate some of the key issues inherent in the standard calculations using climate and material data to simulate thermal response of cavity walls exposed to the reality of varying climate conditions and locations. Hygrothermal analysis has not previously been tested to aid the simulation of thermal transmission due, most likely to a recent focus on hygrothermal assessment for mould prediction and safe construction. However, this paper presents hygrothermal modelling as an ideal solution to the thermal assessment of thermal upgrade design as a result of pre-established model verification.

2. Moisture & Heat Control by Hygrothermal Simulation

The analysis of the coupling of heat and moisture is known as “hygrothermics” (IBP, 2015b). Building performance modelling began in the 1950’s in an effort to calculate net energy demand, analysing the ways in which energy loads could be reduced by building related measures and getting information on the temperature without heating and cooling as this enabled the evaluation of overheating risks (Hens, 2009). Just a handful of models, were able to quantify the air and humidity balances in the building. Instead rough estimates on infiltration and ventilation were used and humidity remained untouched (ASHRAE, 2001).

Building regulations in Ireland recommend that the risks of interstitial condensation should be addressed by following the guidance within TGD Part L leading to British Standard BS 5250:2011. It is recommended here that the risk is assessed with a calculation using the Glaser method, specified in EN ISO 13788:2012. However, this ‘conventional’ assessment method completely ignores liquid moisture transport, for example as a result of wind-driven rain (WDR). More sophisticated one and two-dimensional full heat and moisture models are available that allow modelling vapour and liquid flow, that are transient in nature, that consider moisture sources such as wind-driven rain, rising damp, initial moisture, sorption and de-sorption, interstitial condensation and surface condensation. They are based on procedures set out in EN 15026:2007, and software packages for such assessment are available, for example MOIST, Match, Wufi, Latenite, Delphin and HygIRC (Sanders et al., 2014).

The first guideline on moisture control analysis by hygrothermal simulation was issued in 2002 by the International Association for Science and Technology of Building Maintenance and Monument Preservation (WTA), an association dealing with preservation and renovation of heritage constructions and rehabilitation of the building stock (WTA, 2002). Five years later the European Standard EN 15026 (2007) which is largely based on the WTA guideline was published (Kunzel, 2014). However, both documents do not contain any information on how to deal with small defects in the building envelope. Parallel to the standard work in Europe a slightly more comprehensive standard on moisture control design has been developed in North-America (BSR/ASHRAE, 2008). As a result of numerous damage cases linked to rainwater penetration into constructions with rendered facades, this standard has been the first that proposed the consideration of the effects of small leaks in the exterior finishes of exposed walls (Cheple et al., 2000).

2.1 Review of Simulation Tools

A report by Hens (1996) showed that 37 programs had been developed for Heat, Air and Moisture (HAM) analysis. A review of hygrothermal models suitable for building envelope retrofit analysis was conducted by Corporation (2003). This review identified 45 hygrothermal simulation tools. Delgado et al. (2010) expanded this figure to 57 hygrothermal modelling tools. This list was reduced to 14 hygrothermal models based on their availability to the general public. A critical review of these simulation tools and their level of complexity can be read in their book: (Delgado et al., 2012). WUFI was used in this research however as it has been validated in the field and laboratory more than other hygrothermal simulation tools.

2.2 WUFI (Wärme Und Feuchte Instationär - Transient Heat and Moisture Transiency)

WUFI is a family of software products that allows realistic calculation of the transient coupled one- and two dimensional heat and moisture transport in walls and other multi-layer building components exposed to natural weather (IBP, 2015a). The software has been validated by detailed comparison with measurements obtained in the laboratory and on IBP's outdoor testing field (IBP, 2015a). Both one and two dimensional simulation tools have been validated numerous times using data derived from field and laboratory tests (Künzel, 1995). In terms of heat transfer, WUFI takes into account: thermal conduction, enthalpy flow (including phase change), short-wave solar radiation and long-wave radiation cooling (at night).

Vapour-phase transfer is by vapour and solution diffusion while liquid-phase water transport occurs through capillary conduction and surface diffusion. Convective heat and mass transfer is disregarded in WUFI models. In this case a simplified method of calculation of μ has been used for materials:

$$\text{Vapour resistivity } (Vr) \times 0.2 = \mu$$

The thermal and moisture conditions and transport in buildings and building components are coupled. It is well known that high moisture levels result in higher heat losses, and the temperature conditions in building components influence the moisture transport. The traditional method for assessing the moisture balance of a building component has been the Glaser method (described in TGD Part L and ISO 13788) which analyses the vapour diffusion transport in the component. However, this method does not account for the capillary transport of moisture and for the sorption capacity of the component, both of which reduce the risk of damage in case of condensation. Furthermore, since the Glaser method only considers steady-state transport under simplified steady-state boundary conditions, it cannot reproduce individual short-term events or allow for rain and solar radiation. It was meant to provide a general assessment of the hygrothermal suitability of a component, not to produce a simulation of realistic heat and moisture conditions in a component exposed to the weather prevailing at its individual location (IBP, 2015b). WUFI software requires standard material properties and moisture storage and liquid transport functions. For boundary conditions, measured outdoor climates – including driving rain and solar radiation – are used.

3. Methodology

The methodology used in this phase of the research is modelled around multi-methodological design, incorporating some qualitative research to allow a fuller piece of research as suggested by Creswell (2009). Data collection and analysis through past and present research by others, along with policy design standards, recorded climate data, housing figures, common external wall constructions, standard design calculation methodologies and non-standard yet required design calculation methodologies corresponds well with and suits the theory of a quantitative methodological approach (Corbetta, 2003, Maxwell, 1998, Maxwell, 2012), the research is structured, performing a series of calculations and recording performance data to produce results which clarify the question. A

qualitative approach was used to develop an understanding of the problem and improve methods for the quantitative element of research.

Searches were undertaken of recognised relevant academic and specialist building conservation literature databases through a number of journals and websites of the statutory bodies responsible for the protection of the Irish, UK and European environment. Using the technical indices, namely Technical Guidance Document Part L, the standard calculation methodology for external wall performance was identified as the U -value (W/m^2K). This document then referenced extended documents explaining U -values and materials. Through analysing these documents the U -value calculation was evaluated, gaps in the process established, and solutions identified. U -value calculations are isolated from climate conditions, and thermal transmittance should be representative of in-situ performance. This problem was identified to be resolved using hygrothermal simulations through WUFI 5.3. The existing wall assembly with varying retrofit solutions applied in a Dublin based maritime climate was assessed using hygrothermal simulations in conjunction with examples set out by (IBP, 2013, Künzel, 1995, Künzel, 1998, Little, 2009, Little, 2011). The existing wall structure was verified through visual inspection through a bore scope along with measurements using metric system as an internationally agreed decimal system of measurement. Thus, the following thermal retrofit/upgrade assemblies were chosen for this study (see , , &).

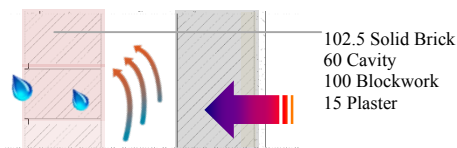


Fig. 1 - Uninsulated Cavity Wall

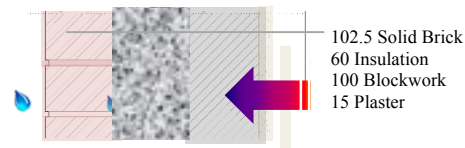


Fig. 2 – Cavity Fill Cavity Wall

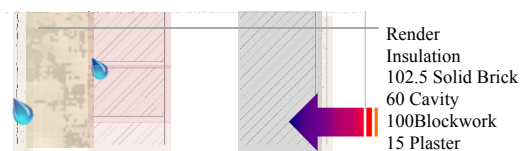


Fig. 3 – Externally Insulated Cavity Wall

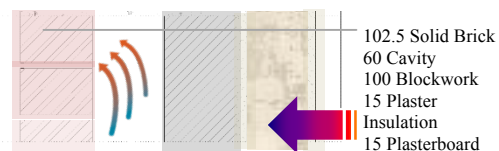


Fig. 4 – Internally Insulated Cavity Wall

4. Retrofit / thermally upgraded fabric performance

The fundamental implication of this research was to determine the effect of moisture content in the existing construction. With moisture, conductivity is affected, altering the assumed dry conductivity of materials. In this paper, the overall construction was simulated over 3 years to establish the expected water content in the wall after a significant period of time (as shown in Fig. 7). The existing wall thermal transmittance was calculated as $1.688W/m^2K$ following calculation procedures within EN ISO 13788:2012. This was then used as the benchmark to compare against.

4.1 Orientation

Hygrothermal simulation was performed to establish the water content expected in each layer of the basic wall assembly, which then facilitated accurate thermal transmission calculations based on the corrected conductivity of the layers. Firstly, hygrothermal simulation was performed on the existing wall assembly for all 4 geographical orientations using a Dublin maritime climate file acquired from Meteotest (providers of weather, climate and environmental data in Europe). This study highlights the effect of combined wind and rain (wind-driven rain or WDR) on the thermal transmission of the existing wall build-up. For the purpose of this paper, the potential worst case scenario for the case study was analysed. As is demonstrated in **Fig. 5** & Table 1, the West façade is presented as the least thermally efficient façade orientation. This is due to a prevailing westerly wind in Ireland, thus driving rain exposure.

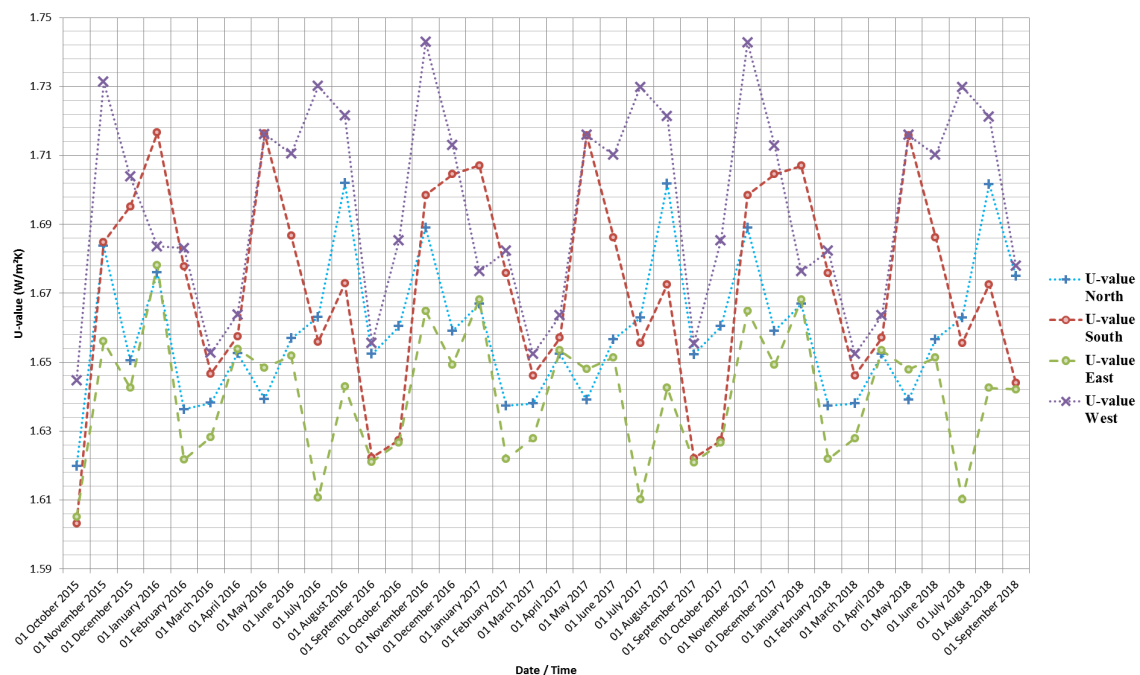


Fig. 5 – Thermal transmittance trend based on orientation. Source: WUFI Simulation.

Table 1. Transient thermal transmission values for all wall types. Source: WUFI.Pro 5.3.

	Benchmark(W/m ² K)	North (W/m ² K)	South (W/m ² K)	East (W/m ² K)	West (W/m ² K)
Avg	1.688	1.859	1.877	1.824	1.913
Min	N/A	1.801	1.777	1.780	1.835
Max	N/A	1.927	1.953	1.875	1.980

Following the analysis of the influence of orientation on thermal transmission, Table 1 illustrates the benchmark thermal transmittance compared against the average transient thermal transmittance based on expected moisture content. Startlingly, the contrast is quite significant, up to 17.2% higher (poorer) than the traditional thermal transmittance and 13.3% higher on average. According to BS 6946, a

significant correction shall be applied when over 3% variation from the original thermal transmittance is encountered. Thus, correction shall be applied to the thermal transmittance in this case.

As mentioned, the existing uninsulated wall assembly must be simulated to assess the water content of each layer to formulate the transient moisture dependant thermal transmission. The simulation was performed on a westerly orientated façade over 3 years to derive a pattern of increased, decreased or steady predictable moisture content (see **Fig. 6**).

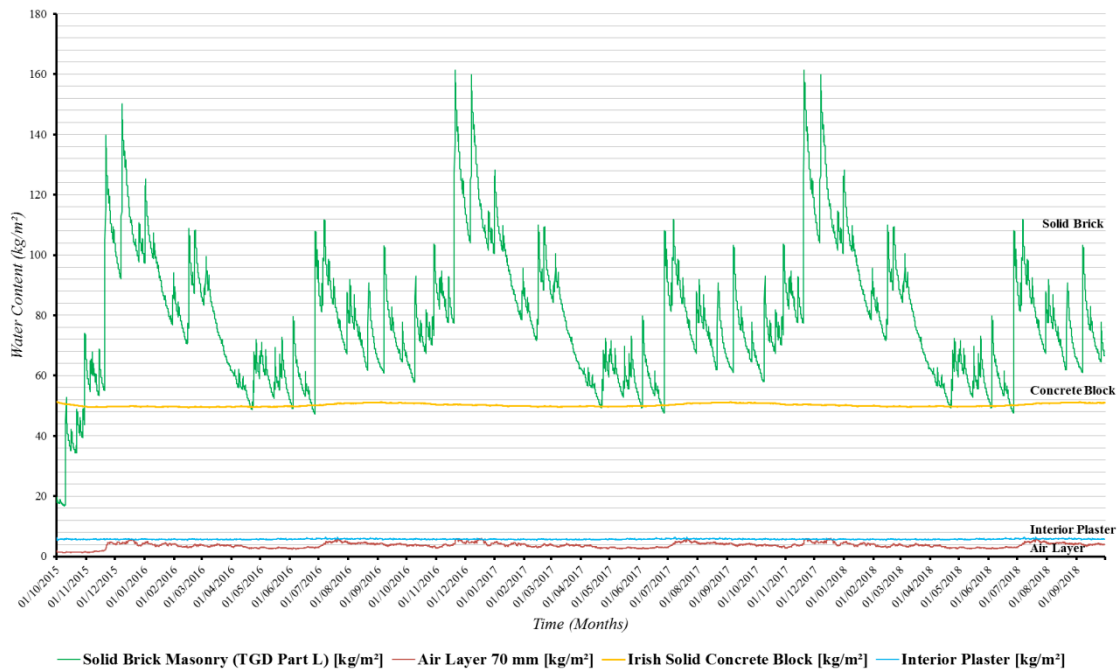


Fig. 6 – Water content of individual component layers

Fig. 6 reveals that the wall did not dry slowly or fully. The WUFI postprocessor analyses hourly temperatures and heat flows resulting from the full transient simulation, taking into account hygrothermic conditions in the assembly which result from exposure to climate and occupant behaviour. This includes the effects of variable material properties (in particular, the effect of the variable moisture content on the thermal conductivity), additional thermal transport processes (such as latent heat transport by vapor flows), additional heat sources (such as solar radiation), and parameters depending on environmental conditions (such as wind-dependent surface transfer coefficients). The postprocessor also computes a monthly transient thermal transmittance, using the formula

$$U = (-Q) / \Delta Ta \text{ where, } \Delta Ta [K]: \text{ Monthly mean value of temperature difference between indoor and outdoor air temperature}$$

5. Retrofit Assembly Simulation

According to TGD Part L 2011, only material alterations require a backstop or target thermal transmittance for existing buildings of 0.60W/m²K. As a target emanating from the overall research, the backstop thermal transmittance as set out in the Sustainable Energy Ireland (SEAI) Better Energy

Homes Scheme for thermal upgrade funding were selected as design targets of 0.27W/m²K for all forms of thermal upgrade treatment to external walls.

Thermal transmittance targets were achieved through the application of insulation on the existing wall assembly. To accurately predict the moisture content and thermal transmittance, accurate material properties were compiled in *Table 2* from (Department of the Environment, 2011), WUFI Pro 5.3, and material manufacturers directly.

Table 2 Table of material data for simulations

<i>Wall Types</i>	<i>Insulation Material Applied</i>	<i>Conductivity (W/mK)</i>	<i>Specific Heat Capacity (J/kgK)</i>	<i>Bulk Density (kg/m³)</i>	<i>Porosity (m³/m³)</i>	<i>Water Vapour Diffusion Resistance Factor</i>	<i>Insulation Location</i>
WT1	Kingspan EPS White	0.038	1130	14.8	0.95	60	
WT2	Gutex Wood Fibre Board (thermoroom)	0.038	2100	131	0.91	2	
WT3	Calsitherm Calcium Silicate	0.057	1303	222	0.92	5.4	Internal Insulation
WT4	Sto Perlite	0.042	850	100	0.96	8	
WT6	Isover Mineral Wool	0.035	840	115	0.95	1	
WT7	EcoCell Cellulose	0.040	2500	70	0.95	1.5	
WT8	Kingspan PIR	0.022	1400	32	0.99	50	
WT9	Kingspan Phenolic	0.020	1880	43	0.95	200	
WT10	Kingspan EPS White	0.038	1130	14.8	0.95	60	
WT11	Kingspan EPS Platinum	0.031	1130	17	0.95	30	External Insulation
WT12	Rockwool Façade Mineral Wool	0.038	1030	135	0.953	1.1	
WT13	Gutex Wood Fibre Board (thermowall)	0.039	2100	160	0.90	2.1	
WT14	Kingspan EPS EcoBead	0.033	1200	11.5	0.95	60	
WT15	Rockwool Mineral Wool EcoWarm	0.039	850	40	0.95	1.1	Cavity Fill Insulation

These insulation materials were then incorporated into hygrothermal models and simulated over a 3 year time frame in a Dublin based maritime climate.

The water content of the wall assemblies did not drop below 15kg/m³ beyond the first month. So, 80% of wall assemblies exhibited a rising water content which stabilized after 3 years, while the remaining 20% of wall assemblies still displayed increasing water contents. These results indicate a trend which may provide a predictable performance applicable to these wall assemblies. Furthermore, water content may be predicted for each wall assembly as analysed in **Fig. 7**.

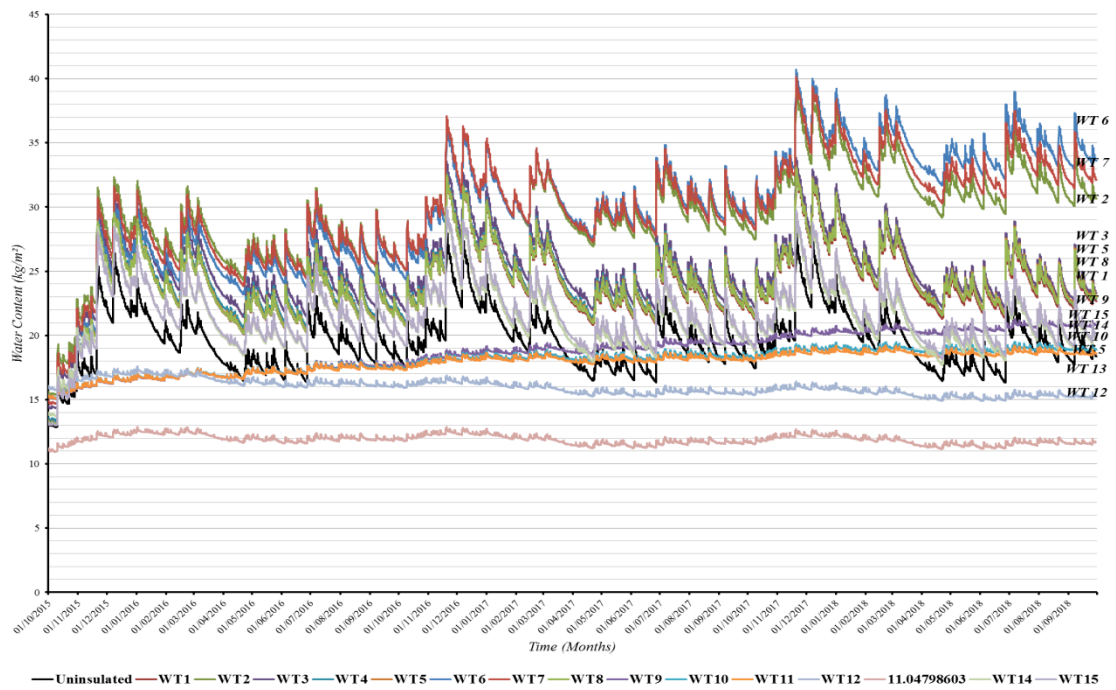


Fig. 7 – Water content in each wall build-up. Source: WUFI simulation

This water content was applied and incorporated to thermal transmission simulations over the same 3 year period in **Fig. 8**.

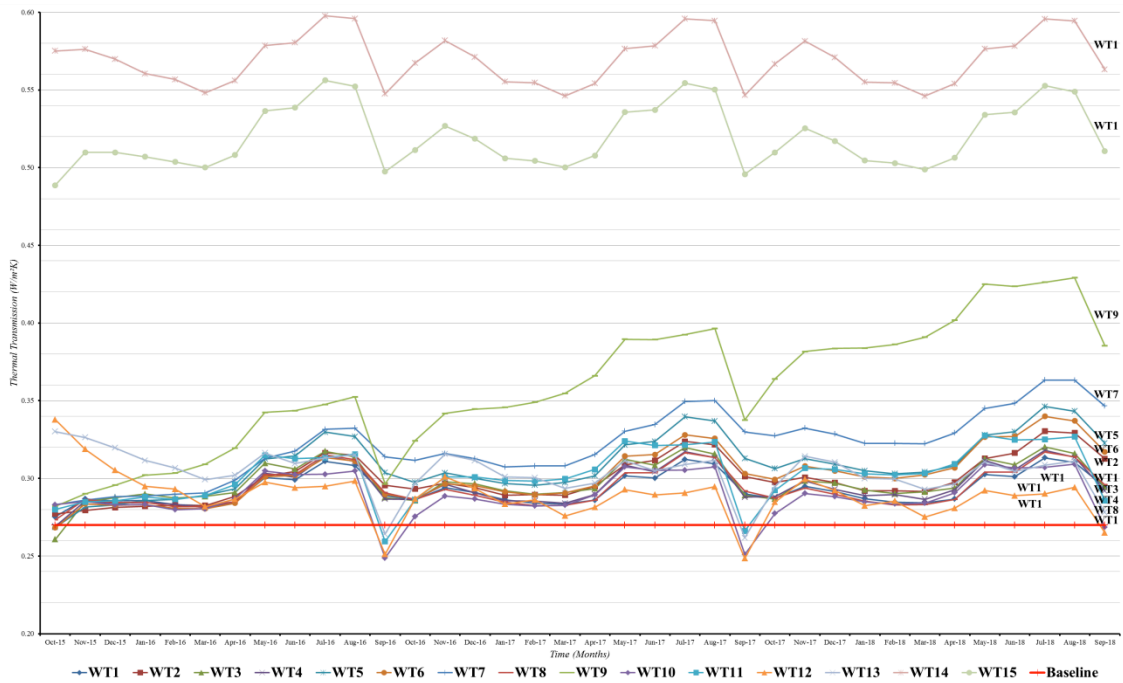


Fig. 8 – Trend of cavity wall retrofit thermal transmittance. Source: WUFI simulation

The fundamental here is that the thermal transmittance for each wall assembly varies dramatically as demonstrated through the hygrothermal simulations in **Fig. 8**. **Table 3** clarifies the findings of **Fig. 8** through a chart highlighting the highest thermal transmission.

Table 3 Transient thermal transmission values for all wall types. Source: WUFI Pro 5.3

	WT 1	WT 2	WT 3	WT 4	WT 5	WT 6	WT 7	WT 8	WTF 9	WT 10	WT 11	WT 12	WT 13	WT 14	WT 15
<i>Avg</i>	0.300	0.300	0.298	0.295	0.309	0.302	0.321	0.294	0.358	0.289	0.302	0.289	0.304	0.570	0.520
<i>Min</i>	0.277	0.277	0.261	0.269	0.269	0.268	0.283	0.273	0.282	0.249	0.259	0.249	0.262	0.546	0.489
<i>Max</i>	0.330	0.330	0.320	0.318	0.346	0.340	0.363	0.317	0.429	0.309	0.328	0.338	0.330	0.598	0.556

Table 3 confirms the inconsistency between the standard thermal transmission calculation and these simulations. The benchmark thermal transmission of 0.27W/m²K was exceeded by as much as 158% in the case of phenolic insulation at maximum peaks. On average, this translates to 33% greater than the benchmark.

6. Discussion

The finding of this stage of the research suggests that orientation has a significant impact on the hygrothermal performance of an external cavity wall. Correspondingly, the orientation will have a significant impact on the thermal transmittance of the same wall assembly. This means that when designing an external wall, designers should focus the design parameters around the West façade for hygrothermal performance and thermal transmittance in Ireland. Furthermore, the findings from the research identify and highlight the disparity between thermal transmittance from standard calculations and the gap between those and the simulations presented here. It is clear that the existing thermal transmittance calculation methodology is imbalanced with a number of flaws in its composition. This could be addressed using the knowledge derived from this research. To further add to this research, verification through in-situ analysis will be carried out on this case study property. Different techniques can be employed to measure in-situ thermal transmittance such as, for instance, thermographic surveys (Albatici and Tonelli, 2010, Fokaides and Kalogirou, 2011), however, the common in-situ measurement methodology uses thermal flux sensors (Peng and Wu, 2008, Desogus et al., 2011).

7. Conclusions

This paper has reviewed hygrothermal simulations along with standard *U*-value calculations as a method to increase credibility and validity of conclusions resulting from further experimental research. This paper is intended to serve as an introduction to issues emanating from a larger research project in order to encourage researchers to more fully study the topic.

The realm of heat transfer and building physics is a question throughout the AEC (Architectural, engineering and construction) sector, particularly within retrofit and refurbishment. This has been confirmed through an examination of previous research in the field, accompanied by personal experience. The understanding gained regarding the influence of external and internal climactic conditions has already, and continues to enhance the product of this research. Adopting hygrothermal simulations, along with accurate material data analysis has allowed a more concise and defined format of information to be assessed. Through the trawling through previous literature available on AEC

research, comparable precedent has been established to set a benchmark for results generated from this research

The findings of this paper identify discrepancies between hygrothermally simulated and standard method U -value calculations. The effect of moisture, wind and solar radiation may cause the thermal performance gap illustrated in the simulated assemblies versus the standard method U -value. Thus, this paper offers a source of information for researchers and designers exploring the performance of external walls to anticipate best practice detailing and in-situ thermal performance values.

Modelling the wall assemblies, with different porosities, moisture storage capacities and liquid water transport coefficients along with accurate climate data gave very different calculated moisture contents and correspondingly, a corrected thermal transmittance. It is clear that, if advanced hygrothermal models in accordance with EN 15026:2007, such as WUFI, are to be used to carry out routine assessments of moisture conditions and U -values in building structures, considerably more construction material data must be made available by manufacturers to achieve realistic simulation results.

Effective research on detailed heat transfer in construction is difficult and necessitates skill and knowledge that is rarely provided in AEC research programs. To understand the full range of challenges faced when doing research, graduate AEC students should take at least one course on building physics, preferably one that covers both heat and moisture control incorporating material and climatic influence.

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Building a Prosperous Urban Future with Reflective Roofing

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Abstract

The great challenge of the next 100 years is to remake our rapidly growing cities into structures that can stand up to environmental changes with residents that are healthier, happier, and more prosperous than previous generations. We often do not think about the roofs above our heads, but making thoughtful materials choices on urban rooftops is a critical, readily-implementable strategy to help meet our new urban challenges. Roofs comprise over 25% of urban space and are readily accessible and easy to upgrade relative to other urban sustainability interventions. With roofing technologies that are currently available, cities can improve their biodiversity, reduce rising urban temperatures, improve health and quality of life, and defend against high energy costs and power blackouts.

One of the key sustainable roof technologies in the market today are reflective, “cool” roofs. Reflective roofing is an ancient concept achieved with modern technologies that have been growing in the market over the last 20 years. Reflective roofing is a cost-effective and easily deployable strategy to cut cooling energy demand by up to 20%, reduce temperatures in and around buildings, improve air quality and health, and cancel the warming effect of atmospheric greenhouse gases. This paper will provide building owners, government officials, and corporate decision-makers with:

1. the tools to quantify the benefits and costs of reflective roofing for buildings, communities, cities, and the planet;
2. an understanding of the available reflective technology options and a look forward at cutting-edge technologies that will be on the market in the next few years;
3. a roadmap for implementing reflective roofing in a variety of contexts via a detailed review of the most successful policies and programs worldwide that have helped spur local adoption of cool roofs including building and energy code requirements, construction specification requirements, green workforce development, and innovative public information campaigns.

Keywords: cool roofs, reflective roofs, urban heat islands, energy savings

1. Introduction

The parallel challenges of warming global temperatures and a mass migration from rural to urban spaces highlight the importance of improving the sustainability of cities. The benefits of sustainability to urban quality of life, economies, energy use and health are well understood, but even leading cities face difficulties in effecting real change quickly in their complicated and interconnected urban ecosystems. An effort to making smarter choices about roofs, such as using more solar reflective materials, can significantly and immediately benefit efforts to enhance the sustainability of the world's urban spaces. This paper will review the benefits, costs, and technologies available to implement cool roofs and describe a few examples of cities that have used reflective roofing to save energy, cut energy bills, improve grid reliability, cool urban heat islands, and improve the health and social welfare of its citizens.

2. Roofs are a platform for urban sustainability

2.1 Good roofs make sustainable cities

While the average person doesn't give it much thought on a regular basis, roof space is an important platform for urban sustainability efforts. Akbari (2008) found that roofs made up between 25% and 35% of the overall urban fabric in the studied cities. This is a significant amount of urban space that, if upgraded with reflective roofing, vegetation, solar power, or some combination, could drive benefits worth between \$0.40 per square meter and \$4.33 per square meter in the form of energy savings, reduced health care and storm water management costs, per Kats (2015).

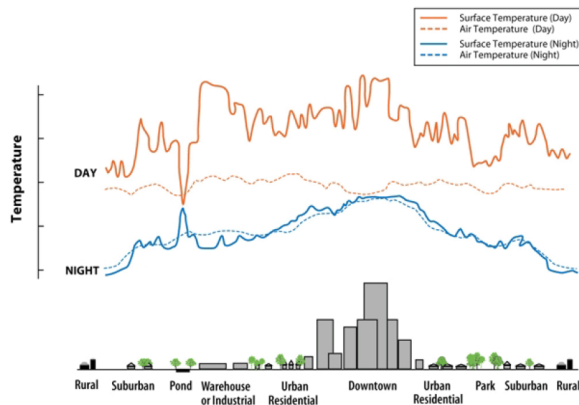
Implementing sustainable roofs can rapidly change cities. Policy makers and building owners have more opportunities to upgrade the sustainability of roofs than other building components or pavements. Roofs are replaced every 15-20 years on average – a replacement rate of 5-7% per year. The benefits to energy use, air quality, health, urban economies, and global climate change mitigation of better roofing start the minute they are installed.

2.2 Urban heat is the defining sustainability challenge for the 21st century city

As Figure 1 from Zhang (2010) shows, cities tend to be an average of 4 to 6 degrees Celsius hotter than rural areas. This phenomenon, known as the urban heat island or UHI, is the result of several factors. Cities are less vegetated relative to rural areas. Buildings block or slow natural wind patterns that would help move heat. Cities are hubs of human activity that generate heat. The biggest contributor to urban heat islands, however, is the predominance of dark, impermeable roofs and pavements that absorb solar energy and radiate heat. UHI is both a

day-time and night time phenomenon. Indeed, Climate Central (2014) found that night-time UHI can exceed 20 degrees.

The world is in the midst of a rapid urbanization. The United Nations reports that the percentage of the world's population living in cities will grow from 50% today to 80% in 2050 – all moving into urbanized space that makes up less than 2% of the earth's surface. Oke (1973)



and Georgescu (2013) found that the increase in urban density and city size exacerbates all of the factors that cause UHI. Currently, excess urban heat is rising at twice the rate of global average climate change.

Overheated cities experience a number of negative impacts that affect almost every aspect of urban life.

Figure 1: *Temperature differences between different levels of urbanization.* Source: NASA Urban heat leads to increased energy consumption

Solar energy absorbed by buildings converts into heat energy that is either transferred inside the building or blown off the roof to heat the surrounding air. For buildings with environmental controls, excess heat leads to an increase in cooling energy demand. In general, the relationship between temperature and city demand for electricity resembles a hockey stick. Below a threshold air temperature, typically between 24 to 27 degrees Celsius, daily energy demand is relatively constant. Demand for electricity spikes dramatically as temperatures rise above that threshold. Akbari (2001) indicated that peak electricity demand increases by 2 to 4 percent for every 0.5 degrees Celsius increase in temperature above a threshold of about 15 to 20 degrees Celsius. In New York City, for example, electricity consumption is 29 percent higher on a 32 degree Celsius day compared to a 26 degree Celsius day. The demand for cooling is generally highest during peak electricity consumption hours, the late afternoon and early evening. Akbari (2005) found that the UHI-related increase in air temperature is responsible for 5 to 10 percent of U.S. peak electric demand.

2.2.1 Urban heat reduces air quality

Decreased air quality is one of the most far-reaching effects of UHIs. Poor air quality, in which the ozone levels and levels of small, inhalable airborne particles (PM-2.5) from nearby coal plants are high, is detrimental to public health and the environment. The World Health Organization (WHO) estimated 21,000 premature deaths per year occur across 25 European

countries because of high levels of ozone (Amann et al. 2008). WHO further estimates that 14,000 respiratory-related hospital admissions in Europe are directly due to high ozone levels.

Urban air quality influences and is influenced by a city's temperature. An increase in temperature corresponds to the rate at which ozone feed stocks cook into ozone. Akbari (2005) found that for every 1 degree Celsius the temperature in Los Angeles rises above 22 degrees Celsius, smog increases by 5%. Figure 2 from Piety (2007) showed how smog forms in a nonlinear fashion in accordance with the maximum surface temperature at Baltimore-Washington International Airport. Each point represents an 8-hour period. At 27 degrees Celsius, most of the points are below the minimum EPA compliance level of 60 parts per billion (noted with a red line in Figure 2). At and beyond 32 degrees Celsius, the majority of points lie above minimum compliance, meaning the amount of ozone is at dangerous levels.

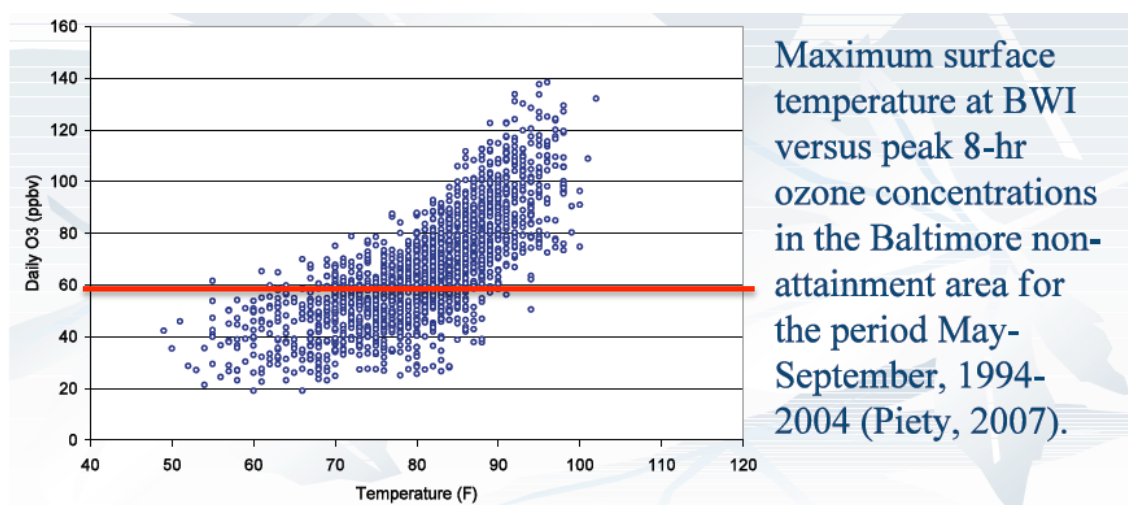


Figure 2: Ozone concentrations by maximum surface temperature. Piety (2007)

2.2.2 Urban heat compromises health

Increased daytime temperature, reduced nighttime cooling, and high air-pollution levels increase health problems and mortality, especially among low-income and elderly populations. In fact, Wong (2012) found that between 1989 and 2000, studies of 50 U.S. cities recorded a rise of 5.7% in mortality during heat waves. The Centers for Disease Control and Prevention (2012) reported that over a 12-year period (1999-2010), excessive heat caused 7,415 premature deaths in the United States. Heat waves in Europe claimed over 52,000 lives in 2003 alone – one of the greatest natural disasters in history.

In addition to causing higher daytime temperatures, urban heat islands keep cities and their residents from cooling off at night. Hotter nighttime temperatures are especially dangerous during extreme heat events. Urban populations are often unable to recover from the daytime heat and become more vulnerable to heat-related health problems in subsequent days.

2.3 Reflective roofing mitigates urban heat

Replacing dark urban surfaces with more reflective and lighter-colored surfaces on roadways, walkways, and roofs is a primary UHI mitigation strategy. The darker a surface, the more potential it has to store heat. A light-colored or reflective surface has a very small potential to store heat because of its high albedo, or reflective ability. Surfaces that reflect solar energy stay cooler, release less heat into the surrounding air, and allow for nighttime cooling in a city.

Cool surfaces are measured by how much light they reflect and how efficiently they radiate heat (thermal emittance or TE). Solar reflectance is the most important factor in determining whether a surface is cool. A cool roofing surface is both highly reflective and highly emissive to minimize the amount of light converted into heat and to maximize the amount of heat that is radiated away.

Most roofs are dark and reflect no more than 20 percent of incoming sunlight (i.e., these surfaces have a reflectance of 0.2 or less); while a new white roof reflects about 70 to 80 percent of sunlight (i.e., these surfaces have a reflectance of 0.7 to 0.8). New white roofs are typically 28 to 36 degrees Celsius cooler than dark roofs in afternoon sunshine while aged white roofs are typically 20 to 28 degrees Celsius cooler.

2.3.1 Benefits of cool roofs to individual buildings

Energy savings potential: Increasing the reflectance of a roof from 0.1-0.2 to 0.6 can cut net annual cooling energy use by 10 to 20 percent on the floor of the building immediately beneath the roof by reducing the need for air conditioning. Levinson 2010 presented an analysis of energy savings in new and old office and retail buildings by U.S. zip code. The analysis found that there are net energy savings in every part of the U.S. (warm and cold climates) except in northern Alaska. Target Corporation, one of the largest American retailers, has experienced net overall energy savings (based on all energy consumed for heating, cooling, lighting and equipment) between 0.5% and 1.0%, depending on location, in their facilities across the USA by specifying white reflective thermoplastic membranes. These energy savings collectively result in several millions of dollars in energy cost savings annually for the company.

Cost savings potential: Levinson 2010 found the average annual net energy cost saving (cooling energy saving minus heating energy penalty) for a white roof on a commercial building in the U.S. is \$0.36 per square meter (\$0.40 in 2015 dollars). Retrofitting 80 percent of the 2.6 billion square meters of commercial building roof area in the U.S. would yield net annual energy cost savings of \$735 million. Globally, cool roofs could save billions of dollars. Kats 2015 evaluated the economic benefits from the installation of cool roofs on municipal buildings in Washington DC and found that cool roofs installed on 2.6 million square meters of municipal

roof space would generate net savings to the city of \$46.5 million (\$17.88 per square meter) in energy cost reductions and avoided health costs.

Improved thermal comfort: In a building that is not air conditioned, replacing a dark roof with a white roof can cool the top floor of the building by 1 to 2 degrees Celsius. Programs to install cool roofs and train proper fan use in Philadelphia led to 3 degree Celsius reductions in indoor air temperature during hot days. These temperature reductions are enough to save lives in extreme heat waves and make non-conditioned work environments like barns and warehouses more usable and comfortable for employees.

2.3.2 Benefits of cool roofs to cities

Reduced summer heat island effect Simulations run for several cities in the U.S. in Akbari (2001) have shown that city-wide installations of highly reflective roofs and pavements, along with planting shade trees will, on average, reduce a city's ambient air temperature by 2 to 4 degrees Celsius in summer months. Reducing urban temperatures makes cities more comfortable and enjoyable to live in and promotes healthier populations.

More resistance to heat related deaths Cool roofs can cool the areas in a building where the risk of death during heat waves is high. For example, there were 739 deaths in the Chicago heat wave of 1995. Virtually all of the deaths occurred in the top floors of buildings with dark roofs. Subsequent heat waves have claimed thousands of lives in the U.S., France, Russia, and elsewhere. Kalkstein 2014 found that 10 percent increases in urban vegetation and reflectivity can reduce mortality during heat waves by 6-10 percent.

Reduced peak electricity demand Cool roofs can improve utility capacity utilization and therefore profitability, reduce transmission line congestion, avoid congestion pricing, and forego the need for additional investments in peaking generation capacity. Rosenfeld et al. (1996) estimated that eliminating the urban heat island effect in Los Angeles a reduction of 3 degrees Celsius could reduce peak power demand by 1.6 gigawatts and save about \$175 million per year (\$268 million in 2015). Approximately \$15 million of that amount was due to more reflective pavements. A 2004 analysis of New York City by the Mayor's Office of Long Term Planning and Sustainability, when electricity averaged \$0.165 per kWh, found that a one degree reduction in temperature would cut energy costs by \$82 million per year. Electricity prices have subsequently increased by over 20 percent. Hoff (2014) found that peak energy cost savings can be double the base energy savings in many cooler climate zones. Most cost benefit analyses have not quantified this important aspect of energy savings until recently.

Air quality benefits City-wide temperature reduction not only makes cities more comfortable, but also improves air quality because smog (ozone) forms more readily on hot days. Simulations of Los Angeles in Akbari (2001) indicate that lighter surfaces and shade trees could cool

temperatures and thus reduce exposure to unhealthy levels of smog by 10 percent to 20 percent. Across the U.S., the potential energy and air quality savings resulting from increasing the solar reflectance of urban surfaces is estimated to be as high as \$10 billion per year.

2.3.3 Benefits of cool roofs to the planet

Global cooling potential Akbari 2008 found that replacing the world’s roofs and pavements with highly reflective materials could have a one-time cooling effect equivalent to removing 44 billion tonnes of CO₂ from the atmosphere, an amount roughly equal to one year of global man-made emissions. Every 10 square meters of white roofing will offset the climate warming effect of one tonne of CO₂. Assuming the average car emits 4 tonnes of CO₂ per year, the combined “offset” potential of replacing the world’s roofs and pavements with highly reflective materials is equivalent to taking all of the world’s approximately 600 million cars off the road for 20 years. Put another way, the cooling offset of global reflectivity from cool roofs would cancel the warming effect atmospheric GHG generated by 500 medium-sized coal power plants over the life of the roof.

3. Reflective technology options

3.1 Reflective Roof Technology Options

3.1.1 Roof Types and Cool Roof Options

Cool roofing materials can be divided in to two categories, based on their intended use. Although some technologies are suitable for both applications, generally they are intended for use in either low ($\leq 9.5^\circ$, 2/12) or steep ($> 9.5^\circ$) slope installations. The requirements for being considered a cool roofing material vary by category and program. Table 1 summarizes the requirements of the two most prominent programs in the USA, California’s Title 24 Energy Code and the Environmental Protection Agency’s Energy Star Program.

Table 1. Cool Roof requirements

	Reflectivity		Thermal Emissivity		SRI
	Initial	Aged	Initial	Aged	
California Title 24					
Low Slope	n/a	0.63	n/a	0.75	75
Steep Slope	n/a	0.20	n/a	0.75	16
Energy Star					
Low Slope	0.65	0.5	n/a	n/a	n/a
Steep Slope	0.2	0.15	n/a	n/a	n/a

In the United States, the reflectivity and emissivity (together, their surface properties) of roofing materials are tested according to protocols defined by the Cool Roof Rating Council (CRRC).

The CRRC includes representatives from roofing manufacturers and other experts. The CRRC's standards are recognized in major building energy codes and list both initial/ as received and 3 year aged values.

Cool roofing materials are available in a wide variety of technologies. The most common low slope roofing materials include coatings, single ply membranes and multi-ply bituminous systems. Coatings are applied over waterproof membrane systems such as dark colored elastomeric single ply sheets or bituminous systems, to provide the desired reflective properties and/or to extend the underlying membrane's service life. Acrylic coatings are most commonly used in these applications. A significant advantage of coatings is that they can be applied to in-place membranes, thereby salvaging the existing materials and negating the need to remove, dispose and replace them, most significantly, the existing thermal insulation. Acrylic coatings have some of the highest initial reflectivity values, with a few products in the low 90 percent range.

Liquid membranes are also available which typically consist of multiple layers of field applied acrylic, polyurethane or other fluid chemistries, incorporating reinforcements. These types of products are particularly beneficial for roofs with difficult access and extensive amounts of roof top equipment and other penetrations concentrated in small, congested areas where roll goods are impractical, such as on high rise buildings.

Combined, thermoplastic single ply membranes, which include both polyvinyl chloride (PVC) and thermoplastic olefin (TPO) materials, represent more than 40% of the low slope roofing market in the United States. The ever increasing demand for energy saving cool roofing materials has been a key driver in their growth over the past years. These materials have initial reflectivity values within the low to the high 0.80 range. They can be applied in a variety of configurations including mechanically attached, induction welded, and adhered. The use of hot air welding to seal the seams of the sheets in roll widths of 8' or 10' allows for high application productivity and low installed costs. Although much less common, some suppliers also offer elastomeric membranes with a white, reflective weathering surface.

Modified bituminous membranes have benefited from the development of reflective granules, and products are now available that achieve reflectivity levels above 0.70. Some metallic surfaced materials achieve values in the same range as thermoplastic membranes and acrylic coatings. Modified bitumen sheets which are typically installed in two or more layers, provide redundancy and a high level of resistance to mechanical damage. A variety of sheets are available depending on the application technique to be used: torched on, adhered with hot asphalt or cold adhesives, or mechanically attached. They are often selected in re-roof situations where their compatibility with existing bituminous materials is advantageous.

Table 2 provides a summary of the initial and three year aged solar reflective properties of the various types of materials available (NOTE: All of these materials have high thermal emittance values, therefore for clarity, only the reflectance values are included)

There are a myriad of cool roofing material options available to choose from. Ryan (2015) noted that there are more than 4,600 products listed in the Energy Star database, and about 2,600 products listed in the Cool Roof Rating Council’s database (2015). With products available across the entire spectrum of technologies, performance levels and price there is a cool roof solution for every need and situation.

Table 2: Reflectivity performance ranges for common roofing products.

Type	Number of CRRC Rated Products	Initial Reflectance			Aged (3-year) Reflectance		
		Average	Max	Min	Average	Max	Min
Asphalt Shingles	58	0.26	0.41	0.13	0.26	0.37	0.16
Build-Up and Modified Bitumen Sheet Roofing	84	0.49	0.88	0.25	0.45	0.8	0.23
Concrete/Clay Tile and Slates	429	0.31	0.82	0.08	0.30	0.74	0.1
Field-Applied Coatings	484	0.80	0.94	0.04	0.68	0.87	0.03
Metal Products	1008	0.36	0.77	0.25	0.36	0.74	0.24
Metal Shakes/Shingles (including Granular Coated Metal)	17	0.31	0.46	0.22	0.30	0.44	0.23
Other Roof Products: Fluid Applied Membrane Roofing	10	0.80	0.9	0.42	0.68	0.78	0.43
Single Ply Thermoplastic and Thermoset Roofing	123	0.71	0.91	0.06	0.60	0.81	0.07

There are alternative approaches to achieve similar effects to high surface reflectivity. Some jurisdictions recognize ballasted roofs as alternatives to reflective membranes or coatings in their regulations. Large stone ballast acts as a heat sink, moderating heat transfer into the building. Vegetated or “green” roofs consist of waterproofing membranes covered with growing medium and vegetation. These roofs provide cooling energy savings and help mitigate the urban heat island effect through a combination of shading by the plant media and evapotranspiration. Some major metropolitan areas are incentivizing the use of green roofs as a means to provide some relief to aged, deteriorated storm water sewage systems which often are tasked with handling water volumes far greater than anticipated when they were installed. Although costs continue to decrease over time, they generally have installed costs that are upwards of 50% more expensive than conventional roofing systems.

3.1.2 Design Considerations for Low Slope Cool Roofs

As with all roofing materials and other outdoor surfaces, cool roofs are subjected to various forms of soiling. Research has shown that the degree of soiling tends to level off or plateau after approximately three years of exposure, which is the basis for reporting aged reflectance and emittance values in the most prominent cool roof rating programs. When accounting for the effects of cool roofs in HVAC and other building physics calculations and assessments, only aged values should be considered.

Akbari (2005) has shown that cleaning of some types of cool roof materials such as thermoplastic membranes can restore practically all of a product’s initial reflectivity it is rarely practical or cost effective to do so. The benefits of cool roofs are clearly reduced by surface

soiling. However, an analysis of all products in the CRRC database with an initial reflectivity of 0.70 or greater (average: 0.82), and an initial emissivity of 0.75 or greater, showed the average 3 year aged reflectivity of these products to be 0.70, with over 90% of the products having an aged reflectivity greater than 0.60. Most modeling on the energy and UHI mitigation impacts of cool roofs is based on an assumed value of 0.55 for aged reflectivity.

Some have postulated that in cold climates cool roof surfaces do not heat up as much as darker materials in the winter months, thereby making them more prone to condensation, and less capable of drying out any condensate that may form. Fenner (2014) reported on a survey of twenty four retail stores in northern US states. All the roofs had mechanically fastened reflective thermoplastic membranes and had been in place more than 10 years. None of the roofs had a vapor retarder. No evidence of condensation was found in any of the roofs. As the Department of Energy (2010) has noted with regards to the potential for condensation in cold climates, "...while this issue has been observed in both cool and dark roofs in cold climates, the authors are not aware of any data that clearly demonstrates a higher occurrence in cool roofs.."

Energy codes are calling for ever greater amounts of thermal insulation in buildings, which some believe negate the energy savings benefits of cool roofs Desjarlais (2012) ran simulations using the "Simplified Thermal Analysis of Roofs" (STAR) model to attempt to answer this question. They modeled a cool white roof, incorporating code mandated insulation levels, for a representative city in each of the USA climate zones to establish the base lines. They then repeated the analysis with a black roof, and found that additional insulation was required in all cases for the black roof to achieve the equivalent energy performance as the white roof (Table 3). Ramamurthy (2015) conducted a field study of 5 roofs with various combinations of albedo and insulation values (up to R48). They found that the most energy efficient roof construction consists of a high albedo membrane over high amounts of insulation at their location in the North Eastern USA, where the number of heating degree days is approximately five times greater than the number of cooling degree days.

Table 3: Additional insulation required for a black roof to achieve the equivalent energy performance as a cool roof

Climate Zone	Representative City	Default R-Value, White Roof,	Additional R Value required for Black roof
1	Miami, FL	20	17
2	Austin, TX	25	16
3	Atlanta, GA	25	11
4	Baltimore, MD	30	10
5	Chicago, IL	30	6
6	Minneapolis, MN	30	5
7	Fargo, ND	35	5
8	Fairbanks, AK	35	3

3.1.3 Cool options for steep-slope roofs

The most commonly used steep slope materials in the USA include asphalt shingles, various types of tiles, wood shakes and metals (which can also be used in some low slope applications). Traditionally, with the exception of white colored products, these materials had modest levels of reflectivity, typically 20 percent or less. There has been, particularly in the residential sector, resistance to the use of white products for aesthetic reasons. However, there have been significant developments in most technologies such as reflective granules in shingles, and advances in cool pigments for use on metal, concrete and clay tiles, to name but a few. A variety of “cool colors” is now available in most technologies, which removes a significant obstacle to broad implementation of the concept in sloped, particularly residential, market segments. Some steep sloped materials are approaching reflectivity levels of some of the more common low slope products.

3.1.4 Advances in Cool Roofing Technology

Developmental work is being carried out in most roofing material technologies to further improve upon the reflective properties of materials. Although still in the early stages, the use of fluorescent cool dark pigments is expected to provide metal roof coatings with unprecedented levels of reflectivity. Similarly, the use of synthetic granules will improve the reflective properties of shingles and modified bitumen membranes. One area of great interest is reducing the degree of soiling so as to maintain higher levels of reflectivity over time. Some suppliers are adopting photocatalytic technologies which trap and remove ground level ozone precursors from the air. In the longer term, shingle type products incorporating “directional reflectivity”, will have a dark, traditional appearance from the ground, while the portion of the product’s surface facing the sky will be reflective. Promising research is also being carried on thermochromic and electrochromic materials, that will shift color as temperatures change, potentially eliminating any winter heating penalty.

4. Reflective Surfaces in Policy

Cities and other jurisdictions have enacted a variety of programs and policies to encourage the deployment of cool roofs. Voluntary programs include awareness programs, volunteer cool coating initiatives, and incentive programs to reduce first costs. The most effective measures to drive a transition to reflective roofing have been cool roof requirements. In nearly all cases, the requirements apply to new roofs and when a roof is undergoing a substantial repair or replacement and include alternative compliance options such as solar PV installations or vegetated roofing. Chicago was the first U.S. city to require cool or vegetated roofs, in 2001. Since then, about half of the 30 largest cities in the U.S. have some sort of reflectivity requirement for roofs. Figure 3 details the evolution of cool roof requirements in the U.S.

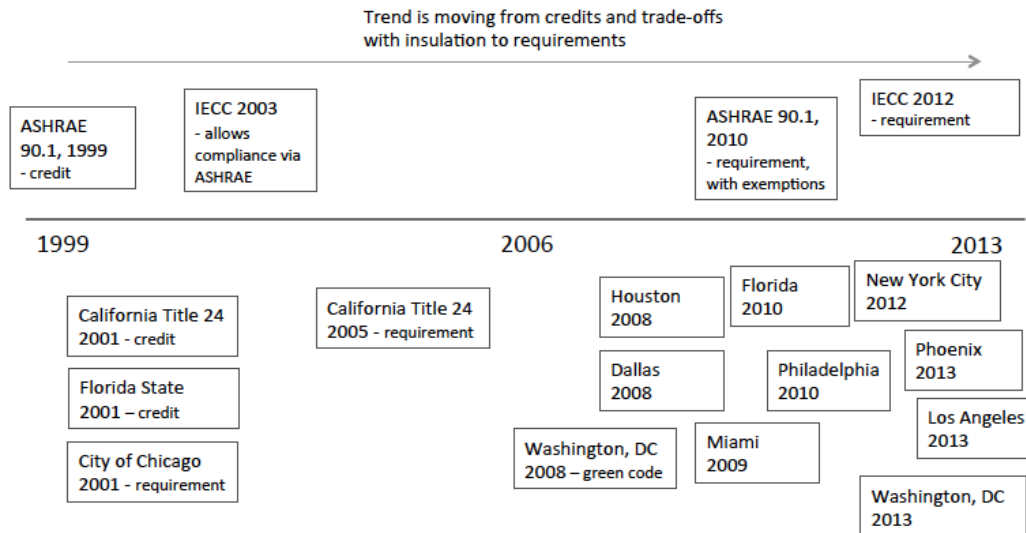


Figure 3: Evolution of cool roof requirements in the U.S.

5. Conclusions

The high concentration of dark heat absorbing roofs and paved surfaces covering significant portions of cities creates Urban Heat Islands (UHI), where localized ambient temperatures are significantly higher than in adjacent rural areas. These elevated temperatures contribute to reductions in air quality and decreased cooling energy demand in conditioned facilities. The additional GHG emissions resulting from the additional power generation compound the air quality issues. The confluence of climate change and the rapid urbanization projected over the coming decades will only exacerbate the problem globally. Broad adoption of cool roofing can play a significant role in mitigating these effects. By reflecting incident solar energy away from roof surfaces, they can moderate the UHI effect and decrease cooling energy consumption, resulting in a significant reduction in GHGs. Cool roofing can also reduce the impact of extreme heat events on occupants of non-conditioned spaces. Cool roofs provide the greatest benefit during peak power demand periods, which can delay or even negate the need to construct the additional power plants in many locations. All of these benefits can be achieved without appreciably changing the way we construct our buildings, and generally without a cost premium over traditional darker materials in all types of low and steep slope roofing technologies. Although a rapid transition to broad implementation of cool roofing strategies would be preferable, requirements mandating the use of cool roof materials in all new construction and during the re-roofing of existing structures will achieve the desired effect over time without additional cost to any stakeholder.

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Green Roof Thermal Performance in Colombia

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Abstract

In some European countries, green roofs have been a research topic stimulating a wide use of these applications. In Colombia, there has been a growing interest in the topic during the last years. The draft Agreement 386 of 2009 made by Bogota's City Council *"By which they are implemented, promoted and encouraged the development of green roof technologies in Bogota"* presented how green roofs and walls can contribute to improve the current environmental problems. Like other cities around the world, Bogota has flooding problems, loss of biodiversity, pollution, inefficient energy use and heat island effect, among others.

This study seeks to examine temperature regulation on a building's rooftop in the city of Bogota, Colombia; due to the influence of a green roof. Locally, there has been no research involving temperature measurements to quantify these effects. Thus, this investigation evaluate the effect generated by the green roof over the surface rooftop under exterior high and low temperatures. Additionally, the study sought to identify possible impacts of green roofing on the waterproofing membrane longevity, due to temperature fluctuations. This document discusses methodology used for temperature measuring along with analyzed scenarios during a four months measurement period. Results suggest that heat flux and thermal performance differences between the green roof and gravel ballasted roofs seem to be influenced mainly by solar radiation, ambient air temperature and volumetric moisture from the substrate. A deeper growing medium or increase on irrigation supply, may allowed the use of larger plants with potentially larger LAI which could reduce canopy air temperatures. This could lead to higher rates of evapotranspiration, and thus a better temperature regulation and further reduce heat flux into the building. Finally, conclusions are proposed about green roof thermal performance in a subtropical highland climate, and its isolation effect on decks or terraces.

Keywords: Thermal performance, green roof, insulation, sustainability.

1. Introduction

Natural cooling techniques in structures or buildings have been used through centuries. In recent decades however its use has been scarce due to the inclusion of air conditioning. The introduction of mechanical systems of air conditioning in buildings with its great energy consumption, has become the standard alternative for refrigeration and air conditioning of interior spaces in buildings today. According to Del Barrio (1998), green roofs do not act as a cooling mechanism, but rather as an isolation one by reducing heat flow through a building roof. It has been found that a well-designed and managed green roof can behave as a device of high quality insulation during summer in temperate zones.

Based on the study carried out by Ascione, Bianco, Rossi, Turni and Vanoli (2013) the following three aspects resume the physical phenomenon occurring during the operation of a green roof:

- Use of the inertial mass of the substrate such as a heat storage.
- Vital processes of vegetation such as photosynthesis absorb heat energy.
- The layers of soil and vegetation may induce ceiling cooling by evapotranspiration.

In addition, these physical and thermal behaviors of green roofs contribute to reduce the heat island effect, as the increase of the temperature in urban areas in relation to surrounding area. Akbari and Konopacki (2005) state that in large cities, this difference can exceed 5°C, since urban areas have extensive hard surface areas that absorb solar radiation and reflect the heat back into the atmosphere. On the other hand, in Teemsuk and Mander (2009) investigation, green roofs help protect roofs from extreme fluctuations of temperature, increasing the structural durability.

During the last decades, due to climate change and especially to the urban heat island effect; generated by continuous removal of green areas, green roofs have proved to be a cost effective alternative due to their ecological characteristics and its contribution to energy conservation in the construction sector. Besides, the application of bioclimatic concepts in the urban sector is limited by the fact that the densely built environment does not allow the use of vertical surfaces for passive solar strategies. Even natural ventilation, the simplest technique, is not always applicable since air and noise pollution in the urban environment lead to the need for airtight buildings. Theodosiou (2003) claims that horizontal surfaces of buildings, such as the ceilings or roofs, receive a high thermal stress during the summer and require strong measures to prevent excessive heat loss during the winter. Green roofs can be a solution to these problems.

1.1 Basic concepts

Çengel (2007) defines heat as the form of energy that can be transferred from a system to another as a result of a temperature difference. Heat transfer always occurs from the medium that has the higher temperature to the lower temperature, and stops when both reach the same temperature or equilibrium. Heat can be transferred in three different ways: conduction,

convection and radiation. All modes require a temperature difference. The two principal ways of heat transfer in green roofs are explained next.

1.1.1 Conduction

Conduction is energy transfer obtained by the interactions between adjacent particles of a substance. It is a heat transfer process based on direct contact between bodies, where no exchange of matter occurs. The process can take place in solids liquids or gases. Experiments have shown that the ratio of heat transfer through a layer flat (\dot{Q}) is proportional to the temperature difference through this and the heat transfer area, but inversely proportional to the thickness of the layer, i.e.: $\dot{Q} = kA * \frac{T_1 - T_2}{\Delta x} = -kA * \frac{\Delta T}{\Delta x}$ [W]

Doing the limit, where $\Delta x \rightarrow 0$, the above equation transforms to the differential form, which is called the Fourier law of heat conduction: $\dot{Q} = -kA * \frac{dT}{dx}$ [W]

Where the constant of proportionality k is the thermal conductivity of the material, which is a measure of the ability of a material to conduct heat. A high value indicates that the material is a good conductor and a low value indicates that it is an insulating material or poor heat conductor.

1.1.2 Convection

Convection is the energy transfer mode between a solid surface and adjacent liquid or gas that are moving and includes the combined effects of conduction and fluid movement. Despite the complexity of this phenomenon, the transfer speed by this mode is proportional to the temperature difference and is expressed in convenient form by Newton's Cooling Law as:

$$Q_{convection} = hA_s(T_s - T_\infty) [W]$$

Where h is the convection heat transfer coefficient, in [W/m²*°C], A_s is the surface area through which heat transfer takes place by convection, T_s is the surface temperature and T_∞ is sufficiently away from the surface temperature.

2. Methodology

This study has been developed to fulfill three objectives: (1) Designing a controlled field experiment to compare thermal performance of green roofs on buildings; (2) Evaluate thermal-insulation effect of green roofs along a vertical temperature profile extending from outdoor air to green roof layers and to the ceiling surface and air; (3) Compare thermal performance of two plant species with different growing mediums. Prior to experiment design, literature review was made of journal published studies investigating green roof thermal performance by experimental measurements. This study is mainly based on the articles by Ascione, Bianco, Rossi, Turni, and Vanoli (2013); Parizotto and Lamberts (2011); D'Orazio, Di Perna, and Di Giuseppe (2012); Hien Wong, Chen, Leng Ong, and Sia (2003); and Getter, Rowe, Andresen, and Wichman

(2011), where parameters such as temperature, airflow, heat, and humidity were measured, in order to calibrate a mathematical model and perform simulations of different scenarios.

2.1 Site and green roof description

The site where the instrumentation was carried out to measure the temperature continuously in different layers of the green roof, was the central cafeteria inside the main campus of the Universidad de Los Andes. The roof is located in the South-East of the city of Bogotá on the lower part of the Hill of Monserrate, at latitude $4^{\circ}36'02.5''\text{N}$, and longitude $74^{\circ}03'54.8''\text{W}$. The area has a climate with 11.5°C average temperature (maximum temperature of 23°C and minimum of 8°C) and 698 mm annual average rainfall, with a bi-modal distribution defined, from April to July and from October to December (IDEAM, 2014). This point was selected, due to the logistical advantages offered, and allowed to install an 110V electrical outlet for the data acquisition equipment. As well as having two different species of plants (Sedum and ferns) the green roof has an area of gravel large enough to have a control as shown in Figure 1.



Figure 1. Universidad de los Andes Green-roof

2.2 Equipment description

Temperature measurements were performed using 8 thermocouples type J, made with an iron and constantan wire. Thermocouples are the most common industrially used temperature sensor. A thermocouple is made with two wires of different materials together in one end, which when applying temperature at the junction of metals generates a very small voltage (Seebeck effect) of the order of millivolts which increases with temperature.

The equipment responsible for carrying out the conversion of millivolt thermocouple temperature measuring is a datalogger, which also allows to store the measured data. The dependency between the voltage delivered by the thermocouple and the temperature is not linear, therefore it is the duty of the electronic instrument designed to show the reading (datalogger), perform the linearization; i.e., take the voltage and knowing the type of thermocouple, see internal tables and match the temperature with the corresponding voltage, as shown in Figure 2.

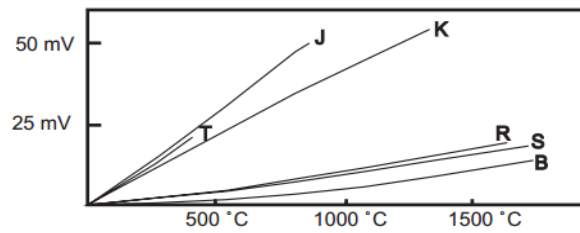


Figure 2. Temperature curve calibration for different types of thermocouples

The datalogger chosen for this research is the OMEGA model OM-USB-5201, which provide eight differential thermocouple input channels and have two integrated cold junction compensation (CJC) sensors for thermocouple measurements. Thermocouples inputs are software programmable for types J, K, T, E, R, S, B and N. An open thermocouple detection feature lets you detect a broken thermocouple. Also an on-board microprocessor automatically linearizes thermocouple measurement data. Finally the OM-USB-5201 has data logging capability, so measurements can be logged to a standard CompactFlash memory card (512 MB). These features allow all parameters to be measured and recorded at 5 min interval.

2.3 Measurement period

Temperature measurements began from late August until the first days of December of the year 2014. During this period of time three experimental stages took place. The first consisted in carrying out preliminary tests on experimental green roof trays arranged in the building of the Department of Physics and Geosciences of the Universidad de los Andes, where various green roof modules were implemented and instrumented in a previous research by Pérez and Groncol S.A. (2013). In these modules in different trays and at different media depths, temperature was measured during a period of time approximately 1 month, starting on 26 August and ending September 23. This first stage main purpose was to familiarize with the equipment and perform preliminary analysis of the thermal performance of green roofs. The second stage consisted of measurements in the ferns on the green roof of the central cafeteria at 4 different depths (Fig. 3); both on the part of the plant cover as well as in gravel cover. At this stage measurements took place for more than 1 month, beginning on September 29 and ending on November 7. Finally, the third stage as well as the second, consisted of measurements both in the part of the vegetation and gravel surface. However at this stage we measured on a Sedum portion of the green roof for approximately 1 month, beginning November 7 and ending on 2 December of the year 2014. Figure 3, shows the sectional drawing of Ferns and Sedum plants in the green roof. The gravel portion has the same distribution of thermocouples, the only difference is that there is no vegetation cover and instead of substrate or media there is gravel ballast.

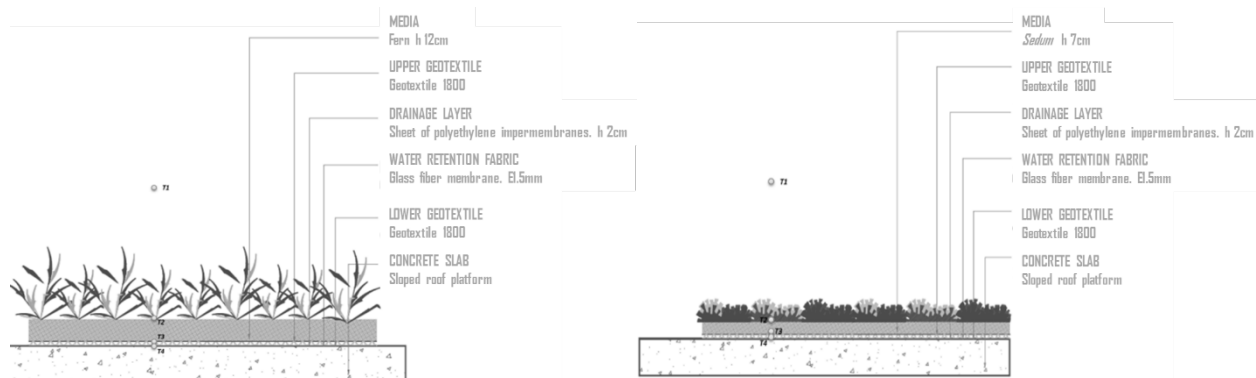


Figure 3. Location of thermocouples on green roof (Ferns and Sedum)

3. Results

Table 1, shows the conventions and location of the thermocouples placed on the plant species Sedum and ferns in the green roof and gravel ballasted roof.

Table 1. Conventions and location of the thermocouples in the green roof and gravel ballast

	Thermocouple	Datalogger Channel	Location
Green Roof (Ferns and Sedum)	1 (T1)	CH0	Temp. 1m height
	2 (T2)	CH1	Plant surface (Ferns and Sedum)
	3 (T3)	CH2	Beneath media or substrate
	4 (T4)	CH3	Water retention roof membrane surface
Gravel Ballasted Roof	5	CH4	Water retention roof membrane surface
	6	CH5	Beneath gravel
	7	CH6	Gravel surface
	8	CH7	Temp. 1m height

3.1 Ferns

Figure 4 shows temperature measurements results in the Ferns of the green roof at 4 different depths, always comparing with the control temperature of the gravel ballast. It can be observed that the day where the maximum recorded temperature arose was on 12 October, whilst the day where the minimum recorded temperature appeared was on September 30. Below are the results at the 4 different depths, where the first graph shows that the ambient air temperature is the same measure from 1m height of the ferns and the gravel, this fact confirms the validity of the measurements, and allows to analyze the rest of the data collected and draw conclusions on the thermal performance of a green roof.

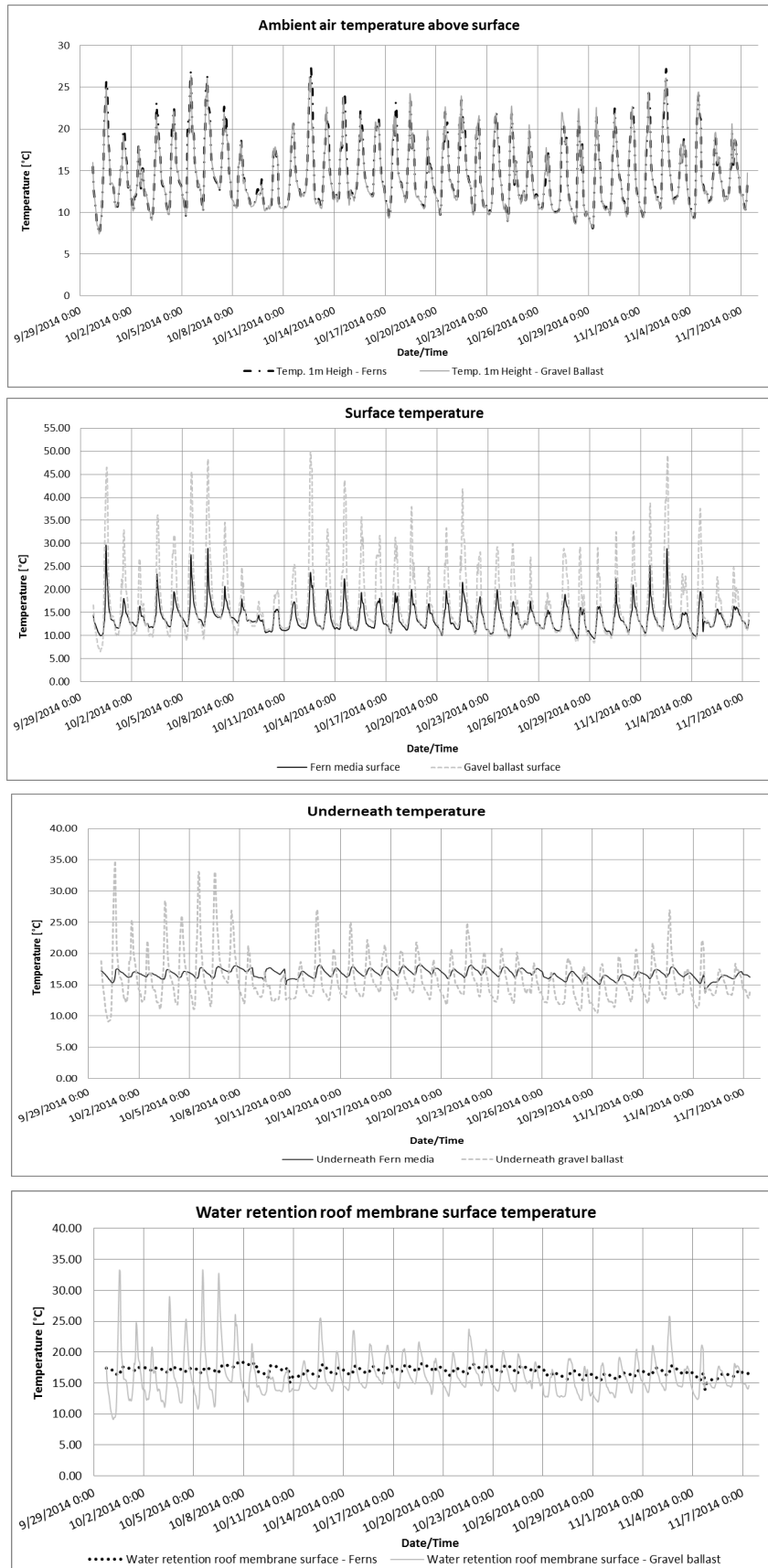
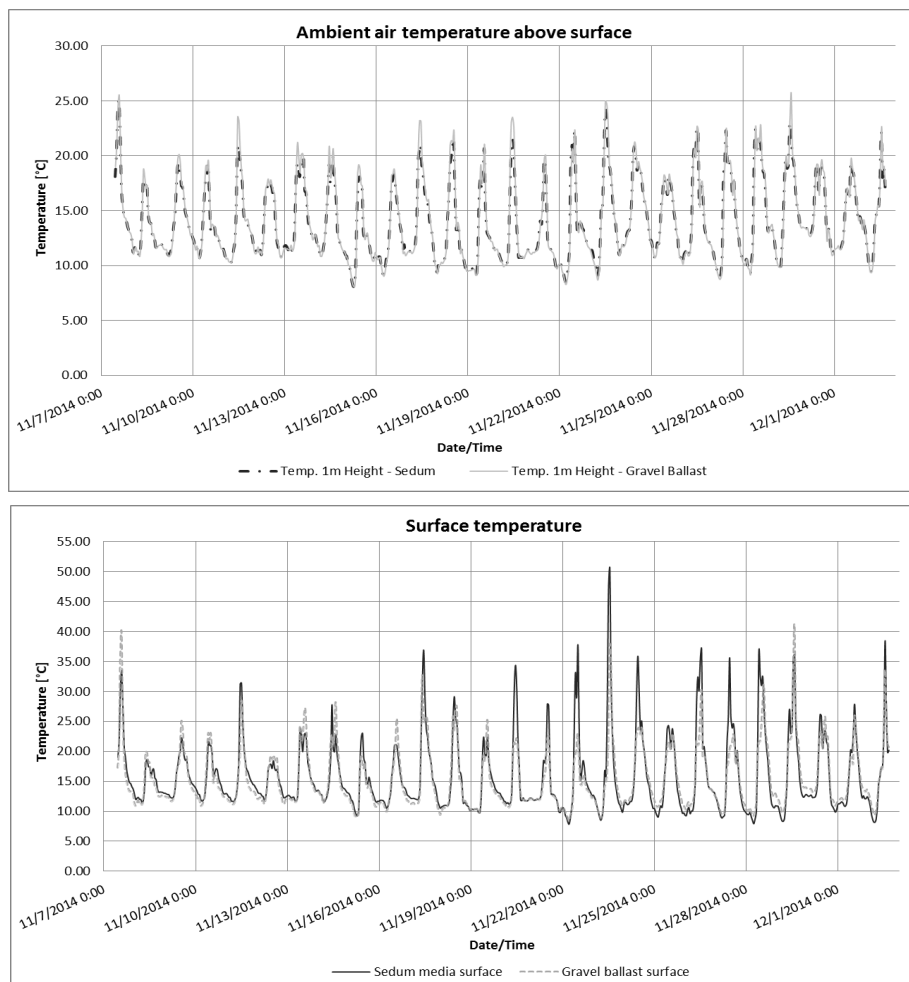


Figure 4. Ferns temperature measurements at 4 different depths

As expected, this maximum temperature was recorded on the surface of the gravel (Ch6), which in theory should gain much more heat than the surface of the substrate or growing medium due to shading from plant canopy and transpiration cooling provided by the plants. This phenomenon leaves a transcendental factor in evidence, and is the important potential function that complies the foliage of the plants against temperature regulation and therefor heat transfer to a roof ceiling.

3.2 Sedum

Figure 5 shows temperature measurements results of the Sedum at the same 4 different depths as the ferns. In this case, the day where the maximum recorded temperature arose was November 23, whilst the day where arose the minimum recorded temperature was 28 November. Following are the results at the 4 different depths mentioned above.



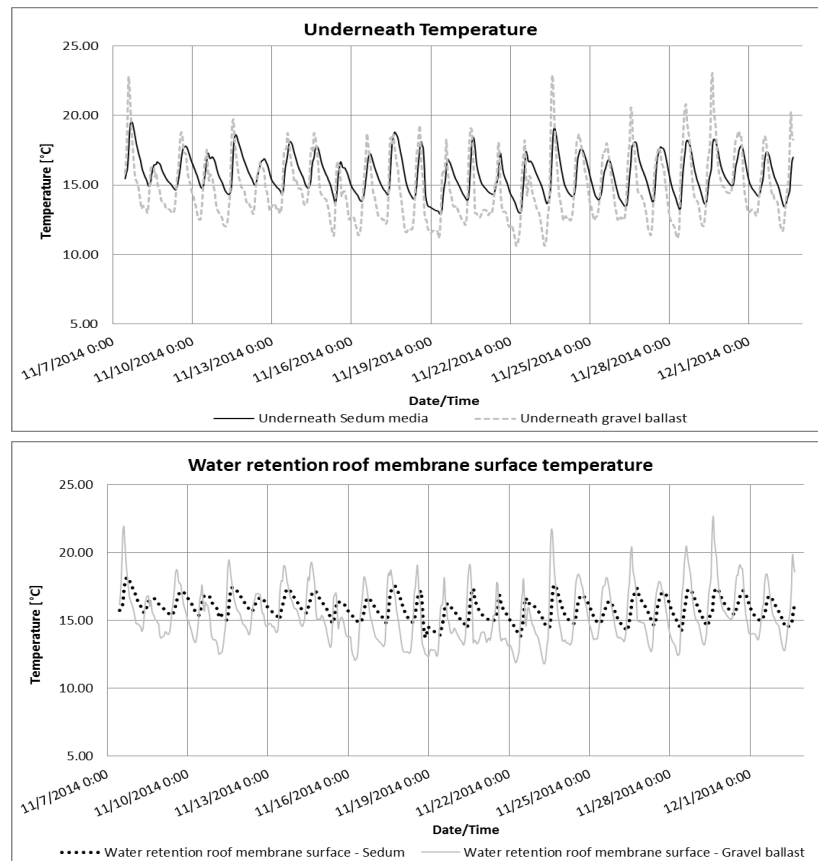


Figure 5. Sedum temperature measurements at 4 different depths

Unlike measurements in the ferns and contrary to what was expected, the maximum temperature was registered on the surface of the growing medium beneath the plants (Ch1) rather than in the surface of the gravel (Ch6). In this case the Sedum has less plant canopy (LAI) compared to ferns. This generates less shade and therefore heats up much more the substrate surface than the gravel ballast.

3.3 Heat transfer

In addition to the results of the measurements of temperature shown above, it was estimated the flow of heat that is transferred to the concrete slab both by gravel and green roof with ferns and Sedum. For this calculation we used the Fourier law of heat conduction explained above in the theoretical framework. Although heat transfer occurs by the combined effect of convection and conduction, in the next analysis we only took into account the conduction effect.

To calculate heat transferred from the surface of the gravel and green roof to the concrete slab, it was necessary to consult the literature for theoretical values of thermal conductivity (k) of gravel and a typical green roof substrate. For the green roof the study of Sailor, Hutchinson, and Bokovoy (2008), establishes that thermal conductivity of a substrate varies depending on its humidity, where k is between 0.25-0.34 W/(m*K) for dry samples, and between 0.31-0.62 W/(m*K) for wet samples. The adopted value of k for the substrate was 0.41 W/(m*K), based in the research by Becker and Wang (2011) where they used this value and also turns out to be a critical value, since corresponds to a humidity of 82% of the substrate. On the other hand, the

thermal conductivity value adopted for the gravel ballast was 0.27 W/(m*K), since this corresponds to the value of k for dry sand according to the ASHRAE (1967), and was also used on Becker and Wang (2011) research. The depth of the fern substrate is 12cm and the Sedum growing medium is 7cm, whilst the gravel ballast is 5cm thick.

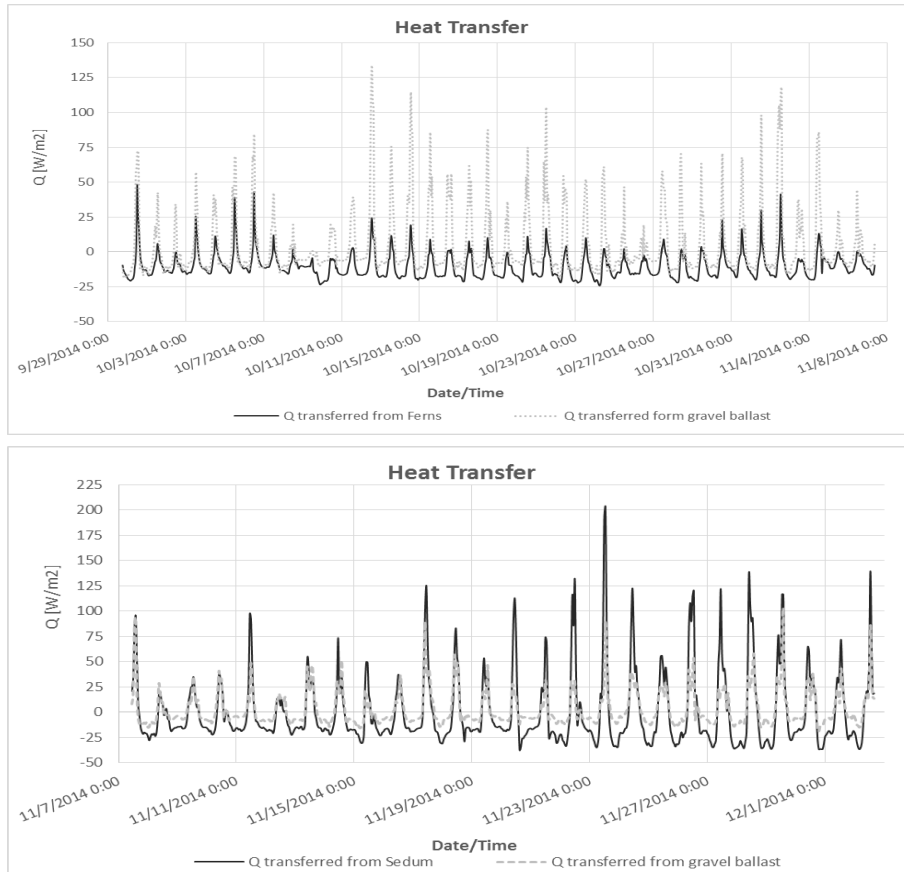


Figure 6. Heat transfer by conduction in Ferns and Sedum

Figure 6 shows heat transfer in ferns is much lower than in the Sedum. Heat negative values indicate that the flow is leaving the building, i.e., the building is losing heat. While positive values of Q indicate that the flow is entering the building, i.e. the building is gaining heat. Calculating heat flow allows to see the way in which heat travels through the green roof and gravel ballasted roof over time. This is useful to understand if green roofs have a better thermal performance than a control ceiling (gravel). However, values of heat alone do not express the overall thermal performance of green roof in comparison to gravel. To quantify the amount of heat that the green roof prevents or avoids the building loses in cold weather and win in warm weather, heat flow values were converted into gained or lost energy per square meter of roof. Heat flows are in W/m^2 , therefore to convert them to an amount of energy transferred, heat flow must be multiplied by the period of measurement in seconds.

$$\frac{\text{Energy Gain or Lost}}{m^2} [MJ/m^2] = Q_m * t_m$$

Where, Q_m is the average heat flux in the period of measurement, and t_m is the number of seconds in the period of measurement.

4. Discussion

During the second experimental stage, Ferns portion of the green roof lost in average 34.09 MJ per square meter. This means that on average the effect of the green roof implementation with ferns prevents the structure to gain heat or produce an upward heat flux from the concrete slab toward the surface of the substrate. On the other hand, throughout the third experimental stage, both Sedum and gravel gain heat. Sedum gain in average 0.35 MJ of energy per square meter. Hence on average the effect of the implementation of the green roof with Sedum prevents the building gaining 6.04 MJ/m², due to the roof portion with gravel gain in average 6.39 MJ/m². In both experimental stages, the portion of control roof (gravel) gain more energy than the one with green roof (Ferns and Sedum). This let us conclude that on average the effect of having no vegetation cover in the portion of gravel produces the building roof to win heat or gets hotter through a downward heat flux from the gravel surface onto the concrete slab. A deeper growing medium like in the Ferns substrate, allowed larger plants with potentially larger LAI to grow, which could reduce canopy air temperatures and further reduce the heat flux into the building.

5. Conclusions

Results demonstrate how roof temperatures and heat flux are influenced by a green roof in Bogotá, Colombia during a period of time of almost 6 months. The investigation is worthy because most research focus on green roof thermal performance in seasonal places or with temperate climate, but Bogotá has a very steady weather over all the year without no seasons. In the case of this study heat flow was calculated only by conduction for each stage of measurement which must be very close to the total transferred energy flow in a conventional roof. A more complex model that also considers the transfer of heat by convection and radiation would be needed to quantify and understand the total flow that moves through the substrate and vegetation cover to the concrete slab. For this reason, convection and radiation heat flows were not considered, and also the equipment used only allowed to measure the transfer of heat by conduction.

In terms of obtained results, it can be concluded that with the shade generated by plant canopy, the temperatures measured on the surface of the substrate, for the two types of vegetation were lower than measurements on the surface of the gravel ballast. The maximum decrease in temperature caused by the plants was around 25°C. The temperature measured under the vegetation varied according to the LAI of the plants. Heat transfer through the control roof (gravel) was greater than through the green roof. Thermal benefits generated by the green roof were the combined effects of the depth of the layer of substrate and vegetation. The damp medium can provide an effect of additional insulation on the roof during all day, whilst vegetation mainly provides protection against solar radiation.

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Measurement Of Residential Building Airtightness Using The "Blower Door Test" And Its Relation With Indoor Air Quality

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Abstract

Airtightness and control of the internal ventilation are among the main factors to be considered in order to evaluate the energy efficiency of a building; moreover, they both strongly influence indoor air quality. Building airtightness has several advantages, such as the reduction of uncontrolled passage of cold draughts and of interstitial condensation. Non-adequate building envelope airtightness can cause mould formation. Some moulds are not infectious, while others produce toxic substances called “mycotoxins” that cause serious infections in more vulnerable people. Other types, such as Cryptococcus, may instead endanger everyone’s health. The sick building syndrome is one of the unpleasant consequences of uncontrolled air draughts, which contribute to the distribution of spores within the environment. Therefore, in order to verify the energy and environmental performance of the building related to airtightness, the “Blower Door Test” is used to measure the hourly rate of air exchange caused by the inaccurate installation of doors and windows, to the presence of passing pipelines or to common construction defects. The test is carried on closing all the openings and placing a fan as temporary replacement of a door. The test, carried on with the aid of a thermal imaging camera to identify the critical points and optimize the airtightness, gives general information about the construction quality. The paper presents the testing method and the results of air permeability “Blower Door Test – Method A”, carried out on March 6th, 2015 at a private residence located in Fiume Veneto, PN, Italy. The test verified that the value fell within the limits for the building certification according to the CasaClima A Protocol. The paper wants to highlight how an appropriate level of building airtightness, together with a mechanical ventilation system, allows reducing heat losses but also contributes to improve the quality of indoor air with the reduction of pathologies for users.

Keywords: Blower Door Test, airtightness, Indoor Air Quality, mechanical ventilation, Sick Building Syndrome

1. Introduction

Airtightness is one of the most relevant features to optimize the technical performance of the building envelope. Proper design and construction of air-tightness of the envelope ensures:

- The reduction of energy losses for ventilation;
- The reduction of energy requirements;
- The thermal protection of the envelope, in order to avoid sudden changes in temperature;
- The absence of passage of sound in an uncontrolled way;
- The reduction of any external or internal pollutants, due to the masonry (formaldehyde, radon, pentane, etc.);
- The absence of uncontrolled air currents;
- The correct functionality of the ventilation system;
- The absence of interstitial condensation and the consequent deterioration of the structures or the growth of hidden mould or brown rot.

PassiveHaus Institute indicates that in the presence of a slot of 1 mm and 1 meter in length, the formation of a mould amounts to 360 g of average water per day in presence of an internal temperature of 20° C and 50% of Relative Humidity (RH) with 0° C outside and 80% of RH. The mould mechanism is well explained in an article of WBDG – National Institute of Building Sciences USA (Morse, Acker 2014) and correlated with the absence of air tightness (*exfiltration*). Condensation triggers the formation of fungi in wood buildings: one of the most important brown rot fungi is Basidiomycota (Palanti) that, according to the National Institute of Health (Mondello 2008), can cause cryptococcosis, pulmonary mycosis that may occur in patients already immunocompromised. During summer, as also indicated in Morse, Acker, the same mechanism in the opposite direction causes the entrance into the room of the spores (*infiltration*). As the pollutants from the inside of the wall can enter in the internal environment, in the same way the interior pollutants can stop in uncontrolled cracks proliferating in the presence of mould and determining the possibility of concentration of further biological mass. In buildings where the tightness is improved, certified with blower door test, and in presence of a mechanical ventilation system, users are positively affected by better environmental conditions (Voci 2014).

The “blower door test” evaluates the airtightness of a building. The method determines the hourly rate of air exchange caused by gaps in the building envelope, due to the inaccurate installation of doors and windows or to the presence of cables and pipelines passing gas, or general construction defects. The test is performed closing all the openings to the outside, including air inlets on the walls of the kitchen, and powering a fan placed in temporary replacement of a window or of a door which lowers and raises the pressure within the interior volume; instruments that measure the pressure difference between inside and outside and the intensity of the air flow are connected to the fan. The measurement is corrected considering the atmospheric pressure, the temperature outside and inside of the building and the wind speed. The test is performed with the aid of a thermal imaging camera to better identify the critical

points and optimize the airtightness. The test gives a global measure of the building quality construction, allowing to avoid problems such as: interstitial condensation with consequent degradation of building components, unbalance of mechanical ventilation, increase in energy consumption, uncontrolled passage of noise, uncontrolled passage of pollutants from the outside, etc.

The “blower door test” can be carried out according to two methods defined in UNI EN 13829:2002 – “Thermal performance of buildings – Determination of air permeability of buildings – fan pressurization method”, (the current EN at the time of the test, now substituted by ISO 9972:2015): Method “A”, which can be made only when all finishes are complete, including the installation of sanitary, and Method “B”, which can also be carried out in unfinished buildings, with the doors and windows already installed, for early detection of possible losses of the airtightness. It is suggested to use the method “B” at the time of installation of windows and systems already installed, in order to control the structure-frame nodes, the plants passages and more generally any node of connection between different parts of envelope. Since the case study building of this paper was already finished, the Method “A” was used.

2. Description of the building and of the refurbishment

A compact volume characterizes the building, with the main front almost exactly facing south. It is part of a complex of terraced houses in Fiume Veneto, in the province of Pordenone, in a district built in the seventies.



Figure 1: South elevation of the building

The property already made some changes to the building, with the installation of photovoltaic panels and the replacement of the old gas boiler with a condensing one. However, these interventions, despite having brought a reduction in expenses for electricity and a slight

reduction of costs for heating and domestic hot water, had not yet solved the constant and repeated mould growth on interior surfaces. The target of the project were therefore:

- make rooms permanently healthy, both through the control of thermal bridges to prevent the formation of mould, both by the application of new painting in low VOC emissions;
- a great reduction in energy demand, achieved through interventions on the entire building envelope (insulation, replacement of windows and mechanical ventilation with heat recovery on time) and on the plant.

Due to the constraints of the building (PV system already installed, the presence of thermal bridges, permanence of users during works and presence of adjacent buildings), it was decided to combine exterior insulation with a limited internal insulation. Particular attention also has been taken to the proper execution of tightness, both on the perimeter of windows, both closing with sponges to tightness the existing corrugated pipes. The application of the thermal insulation on the outside of the building has brought benefits both in winter and summer; Furthermore, the presence of a staircase for access to the roof allowed to take advantage, during the summer months, of the chimney effect, optimizing the intervention for the typical hot and humid climate of this geographical context.

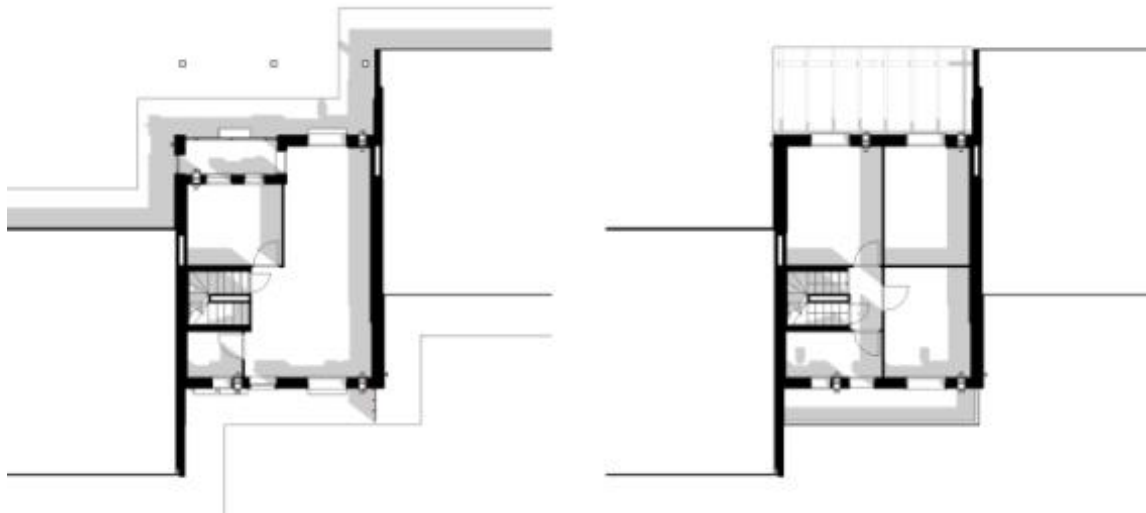


Figure 2: Plans of the ground floor and first floor

North and south façades, being free parts, were isolated with exterior insulation; east and west fronts were, where necessary, insulated inside. Roof was isolated with outside panels coupled with bitumen; over them, washed gravel plates, retrieved before the beginning of works, were then installed. Concerning the internal partition over the cellar, a layer of insulation coupled with plasterboard panels was positioned at the intrados. The thermal bridges caused by different solutions of thermal insulation (internal and external), were solved by extending the outer insulation beyond the limit of the heated volume. This is why the degraded existing external platforms were demolished, thus being able to continue the outer insulation of the walls to the

ground and consequently solving the thermal bridge perimeter. Finally, doors windows provided with abutment to the ground were installed; this guarantees the correct installation of the perimeter and of new triple glazing window with PVC frame, coupled to new rolling shutters box designed to accommodate the thickness of thermal insulation. The works carried out have significantly improved the technical characteristics of the housing that reached the transmittance values given in Table 1.

Table 1: Data of the building elements transmittance after the intervention

<i>Element</i>	<i>Trasmittance value</i>
<i>Wall</i>	<i>0.15 W/m²K</i>
<i>Roof</i>	<i>0.15 W/m²K</i>
<i>Floor</i>	<i>0.49 W/m²K</i>
<i>Window frame (Uf)</i>	<i>1.20 W/m²K</i>
<i>Window glass (Ug)</i>	<i>0.70 W/m²K</i>
<i>Window total (Uw)</i>	<i>1.02 W/m²K</i>
<i>S/V ratio</i>	<i>0.82 m⁻¹</i>
<i>Average trasmittance (Um)</i>	<i>0.23 W/m²K</i>

3. Description of the test

The test was carried out on March 6th, 2015. The instruments used, in accordance with UNI EN 13829:2002 – “Thermal performance of buildings – Determination of air permeability of buildings – fan pressurization method”, were:

- The blower door test system, including air tightness sheet, adjustable fake aluminium frame to be fixed temporary to the door and the fan;
- The control gauge for the measurement of air changes inclusive of data cable, to be connected to the fan, USB cable for PC connection, coloured red pipe to be installed over the sheet outside the building for the control of external pressure, yellow pipe to be connected to the fan for the control of the pressure generated by the fan itself;
- A o-hygrometer to check the temperature and humidity of the air, inside and outside;
- A PC equipped with control software Retrotec FanTestic Pro;
- A camera;
- A thermal anemometer.

Table 2: Test equipment

<i>Type</i>	<i>Model</i>	<i>Technical data</i>
<i>Blower Door Test System</i>	<i>Retrotec</i>	<i>Fan 1000 S.N. Ifn002258</i> <i>Meter DM32 S.N. 401881</i> <i>Software Retrotec FanTesticPro</i>

<i>Thermal imaging camera</i>	<i>Trotec IC 80 LV S.N. 36030527</i>	<i>Resolution 384 x 288 pxl Geometric resolution 1,1 mrad Field of view (FOV) 24° x 21° Standard lens 20° x 15° Software IC-Report DuoVision</i>
<i>Thermohygrometer</i>	<i>Mini MX-RH</i>	<i>Temperature accuracy ± 0.3°C Humidity accuracy ± 3% RH</i>
<i>Portable gauge</i>	<i>HD 2134 with Pitot tube</i>	
<i>Digital camera</i>	<i>Casio Exilim</i>	<i>Resolution 20.1 MPix Optical zoom 6x</i>

To perform the blower door test according to Method “A” all finishes including toilet services must be installed; the building must then be ready to be inhabited. The preparation of the test were as follows: once calculated the net volume of the heated volume, the sheet was installed on a appropriate opening, usually an entrance door; in this case, the used blower door test system was suitable for openings from 74-112 cm to 134-247 cm. The frame jamb must be not less than 30 mm; in this case the test frame must be installed over the frame. The chosen opening should not be exposed to the sun to avoid system overheating and changes of pressure difference between inside and outside in a way not in accordance with the real climate data. For safety reasons, during the installing activities the site was adequately illuminated and provided with supply power, particularly few meters close to the opening used for the test. It is useful having a temperature difference between interiors and exterior so, when the depressurization starts, the incoming air from the slots is recognizable since it has different temperature compared to the surfaces and the indoor air. At the same time, to avoid uncontrolled convective motions and not dependent on the test is useful to not heat any heater or fireplace before the test and eliminate combustion ashes. In order to carry out the test, all openings to the outside (or to cellar, attic, garage, etc.) were closed and the interior doors were opened. In addition, concerning the corrugated tubes, both the interior space between the pipe and electric cable and the space between the tube and the building structure must be sealed. Sanitary discharges were filled with water during the test to prevent from depressurization pumping in smelly gases; furthermore, air hoses have been sealed to prevent the passage of air. During the test, it is strictly forbidden to open the doors between inside and outside, to prevent an uncontrolled speed growth of the fan, resulting in possible failure of the electric motor. Once installed the sheet and prepared the building for the test, the fan, the gauge and its connections to the PC were installed. The following data related to the envelope, essential for the calculation of the air exchange times, were then input into the software:

Table 3: Test data

<i>Fan position</i>	
<i>External opening</i>	<i>Entrance door</i>
<i>Orientation</i>	<i>South</i>
<i>Altitude above sea level</i>	<i>20m</i>
<i>Altitude from the building ground</i>	<i>0m</i>
<i>Building data</i>	
<i>Net volume</i>	<i>343m³</i>
<i>Envelope surface</i>	<i>383m²</i>
<i>Net floor surface</i>	<i>124m²</i>
<i>Wind speed</i>	<i>1 – wind breath - 0.45÷1.34 m/s</i>
<i>Temperatures and atmospheric pressure</i>	
<i>Inside</i>	<i>21.5°C</i>
<i>Outside</i>	<i>14°C</i>
$\Delta\theta$	<i>7.5 K</i>
<i>Atmospheric pressure verification</i>	<i>OK - (UNI EN 13829)</i>

The test was carried out with the following conditions:

- the kitchen hood was sealed during the test;
- heat pumps were not sealed;
- all equipment for ventilation were sealed.

At the beginning of the test the fan was filled on the inner side with a sheet to verify the pressure difference with initial flow equal to zero, with the software set to a predetermined time interval. Once acquired pressure data with flow equal to zero, the membrane temporarily placed on the inner side of the fan was removed and the test according to the Method “A”, that plans to carry out the test first in depressurization and then in pressurization. At the end of the test, the fan on the inside was stopped to check again the pressure with flow equal to zero. The software was set to obtain 10 static pressures at flow equal to zero for 10 seconds each, both before each test (first to depressurization and subsequently for pressurization), both at the end.

11 pressure measurements of the building, first in depressurization and then in pressurization, were acquired, from 15 Pascal up to reach 65 Pascal, with increasing not greater than 10 Pascal. The software was set up to analyse each point of analysis for 20 seconds, for a total of about 4 minutes for each test, during which between 100 and 200 detections were carried out.

During the pressurization phase, in the ranges between -20 and -30 and between -50 and -65 Pascal pressure was not completely stable. This change is the result of the turbulence of the fan due to the conditions of the machine: in the specific case the corridor where the door opened

was narrow compared to the needs of the fan. The values measured during the test in depressurization were mediated according to the pressure and, through the points thus identified, a regression line was identified. The points refer to the test in depressurization are well aligned to the regression line, with a correlation index of 99.59%.

The same test was also carried out in pressurization, identifying a number of sealing points useful to define the regression line for the pressurization phase. Placing in the same graph both the straight line representing the depressurization both the one referred to the pressurization, it can be noted that pressurization give values of exchange air time lower than the depressurization; moreover, there is a shorter distance with the high pressures than low ones.

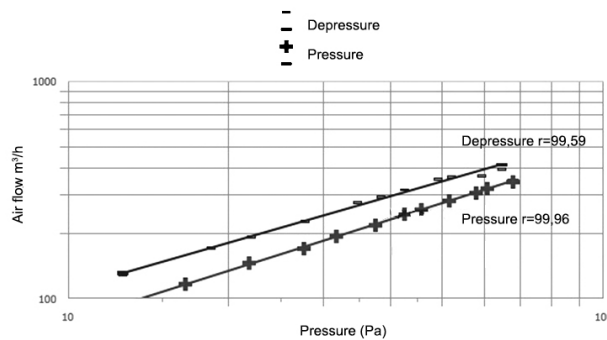


Figure 3: Comparison between pressurization and depressurization lines

In the overall results, during the depressurization air changes times 50 Pa, n50 [/ h] amounted to 1.007, while during the pressurization air changes times 50 Pa, n50 [/ h] amounted to 0.7997.

It is conceivable that air exchange values lower concerning the pressurization compared to the depressurization are dependent from the taping for the sealing air during pressurization, which is “pushed” toward their place, determining a greater efficiency in air tightness. On the contrary, during the depressurization the strips are pulled, facilitating the entry of air from outside. Once the test was finished, results have been obtained by mediating the values of pressurization and depressurization:

Table 4: Results

<i>Air flow at 50Pa</i>	<i>310.0 V50 [m³/h]</i>
<i>Hourly air exchange at 50 Pa</i>	<i>0.9035 n50[/h]</i>
<i>Air permeability at 50 Pa</i>	<i>0.809 q50[m³/h/m²]</i>
<i>Specific flow infiltration at 50 Pa</i>	<i>2.499 w50 [m³/h/m²]</i>

The value of tightness obtained was within the range of acceptability to obtain “CasaClima” label. This Protocol requires that buildings that consume less than 30 kWh/m² per year must

present an air exchange lower than $1.0 \text{ h}^{-1} \pm 0.1$. The value obtained from the test was $n50 = 0.9035 \pm 10\% \text{ h}^{-1}$ and therefore results were within the limits.

The checking carried out during depressurization CRUISE mode also allowed to highlight some critical issues that, in part, have been corrected and that influenced the final result. Such criticalities have been identified using the thermal imaging camera evidencing the cold spots due to entry of air from outside. Among the most critical issues some electrical outlets were highlighted, affected by air leaks and where the sealing can be improved; the shutters of the windows, where not significant leakage occurs compared to the other but, anyway, present; and the vents, that, despite having been taped as required, presented air losses that affected the performance of air tightness.

4. Discussion

The works carried out in the building produced a significant improvement in performance sealing and envelope insulation. The blower door test has allowed us to identify any additional areas that need work, certifying also good airtightness of the refurbished envelope. The thermal imaging camera has highlighted as points of discontinuity in the envelope, such as window frames, electrical outlets or ventilation ducts, can be a weak point for air tightness. They therefore require an adequate design and checking, which can be carried out precisely by using the methodology presented in this paper. In particular, in addition to Method “A”, useful for buildings already finished, the blower door test Method “B” can be used to evaluate the correct installation and sealing of doors and plants.

The benefits from the refurbishment are not limited to the reduction of energy consumption. Actually, the absence of an adequate air tightness causes a uncontrolled passage of air that, in winter, contains a considerable amount of water vapour. This steam, during the migration towards the outside, touches the cold portion of the stratigraphy on which condensation may form. In wooden buildings and in buildings with traditional wooden roof this constant water storage determines an ideal environment for mould growth, including the brown rot. Among the main fungus brown rot is the Basidiomycota (Palanti) that, according to the National Institute of Health (Mondello, 2008), may cause Cryptococcus, a fungal lung infection that can occur in patients already immunocompromised. These same air currents that caused the formation of mould spores can carry spores inside, increasing the number of indoor pollutants (Horn, 2014), up to the limit beyond which could appear the presence of SBS (Sick Building Syndrome). In not historical masonry buildings, with the exception of the situations in which seismic phenomena have caused cracks in the walls, the most critical elements are the ventilation channels not adequately maintained where – like the ventilation systems of hospitals, although in a lower amount – may form over the years a layer of wet dirt that encourages the growth of bacteria. Similar phenomena may also occur in electrical corrugated channels that can serve as conduits for the passage of humid air (toward the outside in the winter and towards the inside in summer). However, while a cleaning operation with the steam ejected by a probe in ventilation ducts can be done, this is not possible in the electrical channels, which remain therefore a potential critical element. Finally, in “traditional” historical buildings (in masonry), where

cracks of the masonry are evident, it is not possible to exclude the deposition of the powder through openings and the formation of interstitial condensation, with the consequent proliferation of moulds and bacteria.

In general, every interstice present in the building envelope may allow the formation of a microbial ecosystem (moulds or bacteria), similar to the one present in domestic dust (Barberan et al., 2015); this phenomenon increases when the airtightness of the building elements is not guaranteed, thus allowing an uncontrolled air flows which favour the transfer of the biological charges and the formation of condensation in the interstices. Also window frames must be included among building elements subject to these issues, since if they are not properly completed or installed, can facilitate the passage of air and the resulting accumulation of dust and dirt at the jamb and seals. These points are likely to the formation of condensation, given the position between inside and outside, becoming a privileged point for the formation of pathogens. Adequate airtightness of buildings is, therefore, an essential technical feature for the protection of healthy indoor air. In this way, it is possible to add a mechanical ventilation system, which allows also to control the exchange of air in indoor environments, allowing the elimination of volatile pollutants.

5. Conclusions

The refurbishment of the building shows how important is not only install renewable energies systems, but also provide the building itself with an adequate thermal insulation, and at the same time ensuring the airtightness of the possible passage points of air between inside and outside. A non-optimum airtightness, in fact, may lead to a worsening of the quality of indoor air, with the consequent diseases for the users. The use of the Blower Door Test allows the control of the airtightness of the housing and at the same time the use of the thermal imaging camera allows to check the presence of air passages through the building, thus allowing to intervene to improve the performance of the building.

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Appropriate Ventilation Solutions for the Iconographic Buildings from the Fifties – A Cross Disciplinary Investigation

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Abstract

In Denmark we currently have an increased focus on preserving the most valuable domestic building examples from the period 1945 - 60. New literature deals with these architectural heritage matters. The authors of this paper argue, that due to question of preservation the buildings physiology is not enrolled in the discussion, and argue that especially this issue can cause a huge damage on the aesthetics of the architectural expression, the facades and the use of the buildings in terms of comfort demands for people living here.

The starting point for the research is preservation, comfort and aesthetics. The primary topic of the survey is the building envelope as a transmitter of external climate to internal climate and vice versa. Three case studies and one reference building as principal renovations are used as information for new innovative and integrative solutions. Analyses and discussions will show a development to the introduction of mechanical ventilation in the building stock with a particular focus on decentralized ventilation systems. To evaluate the retrofitting initiatives a cross-disciplinary corporation between the professions of architecture and engineering are required: this integrated working methodology develops new renovation processes.

Based on both quantitative measurements and on qualitative judgements the cases are analysed comparatively. Parameters such as ventilation solutions in facades are discussed as architectural consequence and value. User interviews will also inform the evaluation. Cases are chosen from earlier research projects and brought into the analysis in order to either see a development or to see more clearly how integrated evaluations of the ventilation and the preserving strategies can lead to a better understanding of an optimized intervention. The paper concludes that interdisciplinary ways of working will improve both architecture and preservation and comfort, and that higher value hereby is created. Furthermore the new initiatives from the industry are shown, which indicates a movement towards innovation of decentralized ventilation solutions.

Keywords: cross-disciplinary cooperation, indoor climate, decentralized ventilation, energy renovation solutions

1. Introduction

The Modern Movement in the 1920s was a reaction to the former stylistic architecture and to the urgent need for low income housing: several architects took the initiatives towards the Modern Movement (CIAM 1933). The modern architectural ideas were among many other ideas defined according to new construction possibilities and industrialized methods: new forms and proportions, flat roofs and no decoration, new materials such as reinforced concrete and steel. New rational building methodology was the new mantra for the movement. The housing areas were laid out in open parks and designed with better flats, where the functionality was the basic fundament for space, distribution and orientation, sun, light and air for people from the working class.

Danish progressive architects were inspired by these ideas and they designed new ways of living at the outskirts of the cities. After WWII there was scarcity of materials, and the modern ideas were moderated to the actual possibilities of solving a huge demand for dwellings. This situation created the modest functionalistic architecture (Nygaard 1984), where architectural ideas were designed and built by Danish local craftsmanship, constructions and materials. The result was a special local translation (Lund 1993) of these modern thoughts into a large number of very fine suburban areas characterized by masonry and very fine architectural design.

This paper will focus on the functionalistic housing built in the period after WWII 1945 – 1960 (Vestergaard 2011), which represents a most valuable treasure in the diverse Danish urban fabric, especially regarding functionality and aesthetical qualities. The period is known for its embedded qualities both in respect to architecture, space and daylight, but also paying respect to traditional materials and modernistic form and detailing.



Figure 1: Typical housing block, entrance, balconies

The buildings are of different value, but a considerable majority belongs to the architectural heritage of the period (Bech-Danielsen 2015). The buildings are characterised by red or yellow masonry and of high aesthetic quality. The facades are aesthetically well designed and the geometry includes important functional detailing such as very efficient ways of dealing with materials and proportions, balconies and details see figure 1. Basically the architecturally expression of these treasures must be kept through the future retrofitting. The building law is reflected by the designs which address demands to staircases, balconies, indoor

design/organisation and size, but also address demands to fresh air and ventilation.

The airflow through the dwellings reflects the building practice of the time and the Copenhagen Construction Law (Københavns byggelov 1939) and was originally operated by separate natural air channels related to the bath and kitchen, see figure 2.



Figure 2: Natural ventilation distributed through facade related to kitchen and bath

Today's urgent demand for retrofitting is caused by the massive backlog in the housing sector, rising energy prices and fulfilling the European targets of CO₂-reduction within 2020 and recently 2030 (EU 2010), which generates a growing demand for new renovation solutions for insulation and air-tightness of the existing climate screen.

By upgrading the climate screen and introducing balanced mechanical ventilation in a number of cases this paper will show, how the comfort in the dwellings is improved through the controlled indoor climate and how the air change has become a parameter to estimate indoor air quality. Balanced mechanical ventilation has been introduced to the existing brick buildings from the 1950s social housing, and development of innovative ventilation solutions have moved from centralized to more decentralize over the last decade (Klint 2009b).

This paper argues that there is a development in new ventilation solutions, towards more sensible solutions, while introducing the balanced mechanical ventilation to the buildings from before 1960. Considerations of where and how to place the ventilation unit will be carried out. Economical perspectives and development towards higher energy efficiency of units will be predicted. The challenge of securing a good indoor climate and a high user satisfaction will be argued. It is realized that very little Danish statistic references in terms of technical ventilation systems in existing multi-story housing, have been carried out. Whereas the statistical investigations have been done in Central Europe regarding office buildings (Mahler and Himmler 2008). However; it is here estimated, that mechanical extraction is the most commonly used ventilation system of today in the multi-story housing in Denmark.

When discussing renovation and architectural heritage, it is very important to establish a holistic understanding and framing. The aim of this paper is to review the complex problem in which the research focus is imbedded. To challenge the discussion it has been chosen to focus specifically on the climate screen as an instrument for better comfort in respect to light, sound, temperature, humidity, energy and air and not to forget preservation of the aesthetics of the architecture. In order to point out broader perspectives the complex challenge is done interdisciplinary.

The research question to explore: How to perform a cross-disciplinary cooperation in renovation of social housing to preserve the architectural expression and the facades and the use of the buildings in terms of indoor comfort?

2. Methodologies

The investigation is based on measurements and simulation from four cases, in which selected parameters within energy renovation has been documented, analyzed and evaluated through a triangular survey of quantity, quality and user experiences from questionnaires.

General and newly developed knowledge from the study of literature are brought into the discussion and compared to the case studies.

In order to open the research and discussion, we have used comparative analysis methodology. The reference and the three cases represents a development in Denmark from 1915 up to 1960, both as architectural and construction wise relatively broad change, but especially the demands to indoor climate and energy efficiency compared with the preservation question.

An integrated research process can be understood as a concept in which the determination and development of a product or a process integrates all relevant parameters, ranging from the aesthetical and the psychological aspects to the technical, the logistical and economical aspects. The authors of this paper have as a team developed the research as an integrated research process, which methodologically builds on tools such as 'Clean Process' (Blyt 2013).

Regarding the content of the research we have focused on architecture and engineering, on architectural heritage, on indoor comfort and on user demands: from this foundation the idea of the abstract has appeared. From the very beginning of this survey the broad discussion has played a driving role for defining the content, the analysis and the discussions of both the problem and the working methodology of the integrated research process.

In order to establish the current state of ventilation principles in existing multistory housing, the conditions are shown, see figure 3 for three different balanced mechanical ventilation approaches for renovated housing and for a reference case characterized by natural ventilation as a normal situation for housing built before 1939.

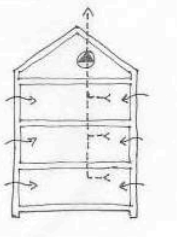
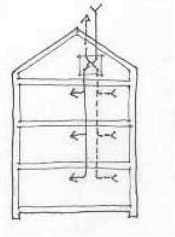
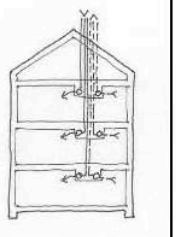
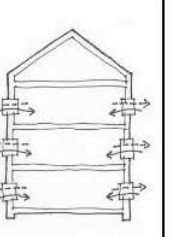
	Reference	Case 1	Case 2	Case 3
Location:	Horsens	Copenhagen	Copenhagen	Copenhagen
Built/optimized:	1945/-	1927/2000	1950/2001	1915/2015
Ventilation system:				
Extraction	X			
Centralized		X		
Decentralized, ceiling			X	
Decentralized, facade				X
Graphical illustration of ventilation solution				

Figure 3: Overview reference case and case 1, 2 and 3

3. Criteria and Findings

The defined parameters for the survey are listed below. Data and sources are quantified and qualified, and user satisfaction is brought into the evaluation. Through the survey the value based importance of the parameters are found.

3.1 Architecture and preservation

It is evident that many of the housing schemes from the 50s are facing modernization, but coordinated knowledge is lacking of how to bring the buildings into the future without compromising the principal preservation values (Dansk Bygningsarv 2015). This brings the headline 'architecture and preservation' as a highly rated parameter into this paper's evaluation of both aesthetic and historic values.

The buildings from the period are obviously challenged as both materials, details, cold bridges, joints and the overall aesthetics and a huge amount of buildings must be kept untouched besides from the installations. At the recently published Danish literature of the period the ventilation question is hardly mentioned, but from several case studies from the 50s it is obvious that the question of air exchange can bring these building's indoor and outdoor expression in danger if not taking properly consideration to the huge damage centralized systems can force. That is basically why we in this paper have focused only on ventilation renewal. Under these circumstances the ventilation devices must be implemented and expressed through a very gentle design. If talking about the façade, the existing façade construction is born with functional perforations such as fresh air canals and filtered masonry to the food store/room. These can be brought in activity in the renovation design.

Through studying this parameter several innovative products have appeared, such as the ventilation window and the integrated parapet solution from Ecovent, see figure 4. Also some products like ventilation windows are very promising constructions for solving the design of the façade (Klint 2009b).

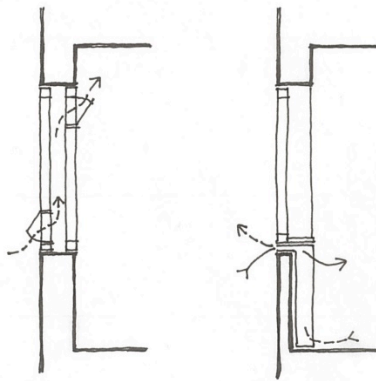


Figure 4: Innovation: Ventilation window and facade solution from Ecovent. To reduce the necessary space required for facade integrated solutions the companies continuingly works with new decentral solutions.

3.2 Space and daylight

Common value based set of norms are existing amongst professional architects regarding a successful experience of architecture: the space should be well defined and proportioned, space should be well lit and the choice of materials should be in harmony and allow the tenants to influence the space with their own selection of arrangement. In addition to this the space should also be designed as extremely functional with good possibilities for furnishing and easy to clean. This means that every disturbing visual installation should be avoided. Both the building regulation in the 50s and a good design ability of the architect shaped the daylight quality. For the future it is important to pay attention to efficient space and to respect the daylight distribution.

The design of the ventilation points in many aspects to the façade ventilation solution. The decentral solution distributing canals to all rooms in the flat, hidden above a hanging ceiling; occupy space primarily in the corridors. Also canals in the rooms can occur. The decentral solutions concentrated under the window inside the heating niche looks very discrete and can be developed to a high aesthetic standard. The decentral solution, described as devices hanging on the wall perpendicular to the façade, will disturb the room feeling. But if integrated under the roof above the window, there will be more discrete possibilities for an acceptable solution. Example of innovation: Change of filters is a huge issue for organizations maintaining the buildings, because this has to be done inside the flat. Also related to this issue it is observed that new innovative filter components are developed. A better insulation value of the window, either 3 layer energy glass or similar will reduce the amount of incoming daylight.

3.3 Energy Efficiency

Energy efficiency in buildings can initiate a mayor renovation, because of the potential annual savings in energy from optimization of the constructions and installations. More than 40% of all

surveyed multi-storey housings in Denmark from before 1960 has an energy label D, which is comparable to a maximum annual heat consumption of 150 kWh/m²/year (Kragh 2015). The heat consumption based on the ventilation of multi-storey housings in the period from 1931 to 1950 is estimated to approx. 25% of the total heat consumption (Wittchen 2004). By using new high efficient counter flow heat exchangers with an efficiency of 80 – 90% such as in the decentralized ventilation systems in case 2 and 3, energy savings as high as 30 - 40 kWh/m² per year of the annual heat consumption can be reduced in multi-storey housings from before 1960 (Tommerup 2004).

3.3.1 Energy consumption - Heat

The case studies and the reference building investigated are supplied with district heating. Figure 5 shows the annual heat consumption related to the net floor area for the 3 cases before and after installing the balanced mechanical ventilation system, and for the reference building the consumption before the proposed energy renovation.

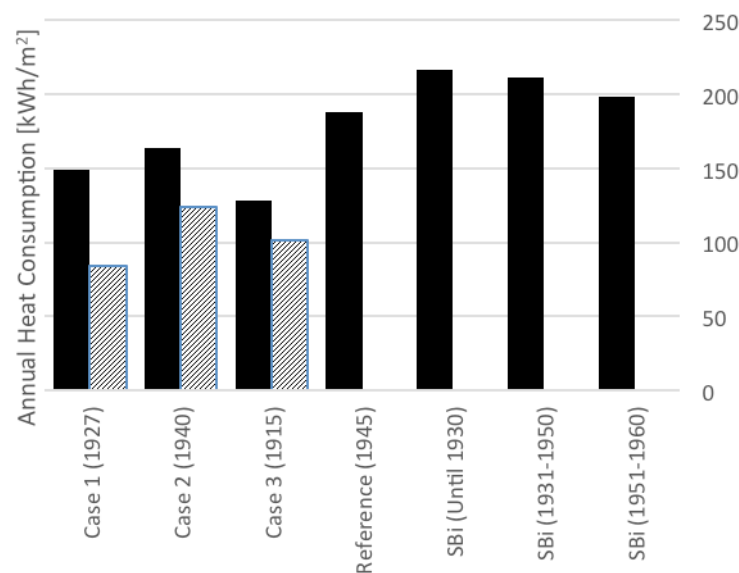


Figure 5: Annual heat consumption before and after renovation

Case 1: This energy renovation is based on balanced mechanical ventilation used with joint intake and exhaust, however there were both central and decentral heat recovery units for the winter combined with natural ventilation in the summer. The energy savings are obtained by preheating the ventilation air in solar low energy ventilation tower to hide ventilation ducts and produce solar energy at the same time.

Case 2: In this case the energy renovation was based on decentralized balanced mechanical ventilation with heat recovery in each dwelling and joint extraction ventilator in the roof space. Solar cells were used to match the electrical consumption of the ventilation units.

Case 3: The energy savings in this case are based on high efficient and low consuming decentralized balanced mechanical ventilation solution in the facade, replacement of the old

windows with new triple layer energy glass and re-insulation of the cavity in the external wall and the story partition.

The average annual heat consumption for multi-story housings in Denmark is based on the SBI-report (Wittchen 2009) on the basis of registration made by the authorized energy labelling consultants in the period from 2005 and 2008. The annual heat consumption in the reference building is based on the registrations from 2013 to 2014 and corrected by the Danish Design Reference Year 2010.

3.3.2 Energy consumption - Electricity

Measurements of the electricity consumption shows that the energy consumption from a decentralized balanced mechanical ventilation unit type V300 from the company Ecovent, which generates a ventilation flow of 45 m³/h, uses less than 8 Wh electricity comparable with 0,2 EUR per day and an annual electricity consumption of 70 kWh. With an electricity cost of 0,2 EUR per kWh (incl. vat) in Denmark the annual cost for a dwelling with two units is approx. 30 EUR (Klint 2009b).

3.4 Comfort measurements

Measurement of the comfort in existing buildings with newly installed balanced mechanical ventilation shows that the indoor climate generally is improved. However, the comfort parameter of draft caused by leakiness in the climate screen or directly from the ventilation system (both the central and decentralized ventilation solutions) haven't been investigated thoroughly in any of the cases even if the user surveys reveals problems within this area.

Some results show an improvement of the draft problems after re-insulation or replacement of the climate screen; however the draft caused by the ventilation system itself hasn't been covered sufficiently. A research paper aiming at investigating air renewal effectiveness of decentralized ventilation devices with heat recovery (Coydon and Pfafferott 2014) concludes, that even if the ventilation system removes pollutions like CO² from the room, the distribution of air and the experience of the air supply is depending on the temperature, speed and direction of the airflow.

3.5 Ventilation rate (carbon dioxide measuring)

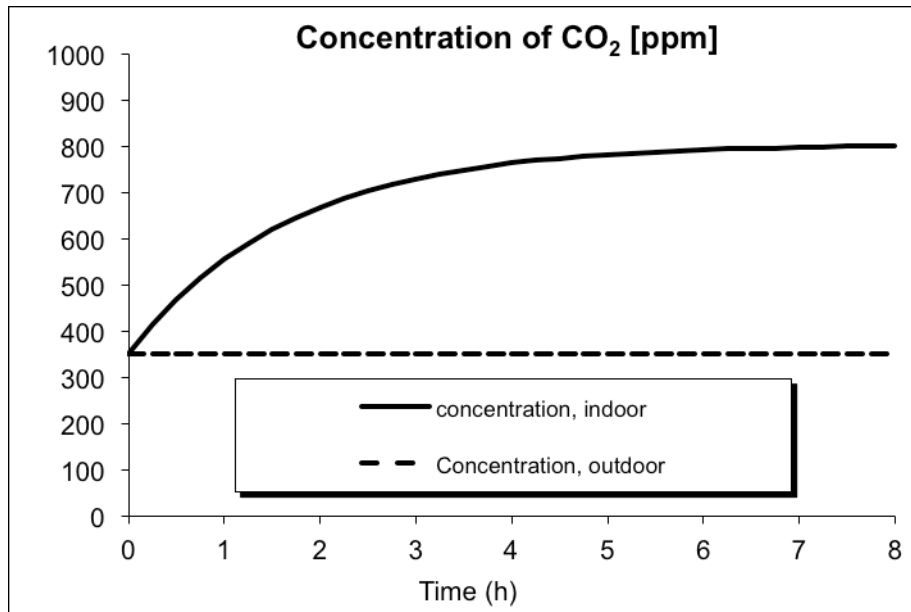


Figure 6: CO₂ concentration progress in case 3.

Figure 6 shows a calculation of the CO₂ concentration in case 3 after the dilution principle with an air change of 0,6 h⁻¹ corresponding to the measured ventilation amount in the dwelling from the decentralized units. The ventilation efficiency of the decentralized units shows very promising results to comply with the demands, which applies for new buildings in Denmark. However; this has to be documented in a larger scale to have been significance.

3.6 Noise emission from ventilation system

There are no qualified measurements of the noise from the decentralized ventilation solutions, however the units are undergoing a progressive development to reduce the risk of noise, such as optimizing and moving the fans to the primary side of the heat exchanger. The user survey showed no discomfort caused by noise, however a German study in 10 office buildings with decentral ventilation solutions the measured sound emissions in some buildings were above the limits of workspace environments (Mahler and Himmler 2008).

3.7 Users' survey

In this investigation a user survey was carried out in the reference building with the purpose of comparing a building with mechanical extraction and high potential to saving energy by installing balanced mechanical ventilation with heat recovery.

User experienced dissatisfaction in %	Very often	Often	sometimes	Seldom	Not at all	No opinion
Room temperature	3	14	41	27	12	3
Vertical temperature	13	26	22	27	12	
Draft by the window	13	19	20	32	16	
Draft generally	8	23	17	25	27	
Air quality, smell	7	25	35	19	14	
Air quality, fresh air	1	4	21	31	43	
Air quality, generally	4	39	43	6	1	7
Sound level from int.	12	40	21	13	4	10
Sound level from ext.	3	30	25	23	5	14
Daylight	3	6	17	43	28	3

Figure 7: User survey in reference building

A similar user survey was conducted in a building after the installation of balanced mechanical ventilation with a decentralized solution integrated over the ceiling in the dwelling (Klint 2009b) see figure 7. In the reference building the tenants were generally satisfied with the indoor climate such as the room temperature, draft and daylight quality. However; they experience dissatisfaction concerning the air quality in general and specific when it comes to unwanted smell and noise from the external environment such as neighboring dwellings.

In the survey conducted in the multi-story housing with newly installed balanced mechanical ventilation the tenants generally experienced an improvement with the indoor climate; especially feeling of draft has decreased after the renovation.

In the decentralized ventilation solution integrated in the facade the tenant experienced a much higher comfort concerning the mix of fresh air and had no discomfort with draft, such as before the renovation.

4. Discussion

A movement in the innovation and development of ventilation systems for renovation of multi-storey housing towards more decentralized solutions such as integrated in the facade has been investigated. The parameters from the findings have been discussed in the triangular study and listed according to the starting point of this paper: aesthetic and preservation as well as indoor comfort forms the two paths of our investigation.

4.1 Aesthetic and preservation

- Ventilation doesn't necessary spoil the facade. Possibilities to reuse the existing perforations of the masonry must be taken into account when optimizing the solution. Innovative measures such as the facade integrated ventilation unit under the window (figure 4) can as an example provide acceptable solutions.
- Users must be involved in the renovation to get a higher acceptance of the installations.

- Decentralized ventilation solutions absorb less space for pathways inside the dwelling, which is an advantage to the users.
- When changing the existing windows to triple layer glass the daylight factor most likely will be reduced, however improvement of indoor comfort generally can compensate for this.
- Potential for saving heat, in this case approx. 25 % can accelerate the renovation rate.
- There is a potential for saving electricity compared to central solutions, which can be compensated for with a limited number of solar cells on the roof.

4.2 Indoor comfort

- The indoor climate generally improves with introduction of balanced mechanical ventilation; however, absence of draft must be identified and solved first.
- Possibility to reach a ventilation rate as for new buildings.
- Noise from the devices must be kept under the requirements.
- Users want individual control of the ventilation, which can be made by decentralized solutions.
- Noise from local noise sources, such as traffic, train etc. can be reduced through insulation of the climate screen.

5. Conclusions and perspectives

In the conclusion of the parameter study and the discussions the authors have identified three essential statements:

1. New interdisciplinary working methodologies will improve both quality, quantity and users satisfaction, and the new results will create value.
2. It is obvious that the movement towards development of decentral ventilation stimulates the industry to develop new and innovative products.
3. From the studies a high level of innovative initiatives has been identified, which indicates a movement towards development of more decentralized ventilation solutions in the introduction of balanced mechanical ventilation in the multi-storey housing in Denmark.

Perspectives

- New facade solutions must be developed in a gentle design to solve the perforation of the façade for decentralized ventilation solutions such as new window designs.
- Incoming daylight should not be compromised when changing the façade

- Draft caused by leakiness in the climate screen or directly from the ventilation system should be investigated more thoroughly with focus on temperature, velocity, turbulence and direction of the airflow.
- The ventilation efficiency of the decentralized units should be documented in a larger scale.
- Measurements of the noise from the decentralized ventilation solutions should be carried out.

Acknowledgements

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How Did We Get Opaque Windows? – Mutual Constitution of Technology and the Built Environment

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Abstract

Construction professionals are continually faced with the challenge of incorporating new technology into their buildings. Much of the current research treats innovations as a discrete entity, thereby overlooking the system properties of many innovations. Implementation often involves extensive accommodation of both the technology and the building. Failure to appreciate this poses significant challenges to the project team, with unintended consequences for the project as a whole. A social construction of technology (SCOT) approach is used to explore the integration of Building Integrated Photovoltaic technology (BIPV) on a commercial project. By exploring the succession of problems and solutions shaping the uptake of BIPV, the analysis also identifies a number of distinct decision modes, including: discrete, conventional and integrated decision making. The first two often contribute to unintended consequences, knock on effects and lock-in, whilst the third is essential for sustainable design. Whereas much of the literature linking sustainability and integration focus on integration across disciplines, this paper links emphasises the need for a holistic understanding of the overlay of different systems constituting a building, including renewable technologies.

Keywords: BIPV, Projects, Innovation, Social Construction of Technology, Co-development

1. Introduction

Construction professionals are continually faced with the challenge of incorporating new technology into their buildings. While much of the research into innovation treats technologies as self-contained entities which can be inserted directly into a building, experience suggests that the process is often much messier. This is especially the case with many of the recent renewable technologies which are systems with multiple components rather than single units. It can also be ascribed to the lack of fit between the requirements of the technology and standard building designs and practice. Far from a simple process, implementation often involves extensive accommodation of both the technology and the building. Failure to appreciate this often poses significant challenges to the project team; decisions concerning a particular design feature in either the technology or the building often throw up new problems, with unintended consequences for the project goals and for the building as a whole. This paper explores these issues by focusing on the micro-level dynamics accompanying the incorporation of Building Integrated Photovoltaics (BIPV). In doing so, it documents the mutual constitution of the technology and the building.

The challenge of green building is often treated as a problem of project team integration, with the focus being on professionals and their procedures and competencies. While this view captures important issues, the focus on professional roles and formal procedures obscures the complex decision making processes which explain how and why challenges are met. In addition, it masks adjustments to both the innovation and the building which accommodation produces. Little attention is paid to how innovative technologies involving cross-disciplinary issues affect the building in which they sit and the processes by which they are installed. What is missing is an understanding of how these interdependencies and the ways they are accommodated come together to shape both the technology and the building.

BIPV offers an example of a technology which is integrated into a building during construction rather than being bolted on during construction. As such, the incorporation of the technology necessarily involves extensive accommodation at many levels and in many different ways as it interfaces with different aspects of the project and its components. These accommodations can be in the form of technical adjustments or through changes to standard designs or ways of working. These technical, design and process-management issues are often treated as distinct and separate but in practice are interrelated.

This paper uses the Social Construction of Technology to explore the ongoing accommodation of both the BIPV technical system and the building. The advantage of this approach is that it draws attention to the succession of problems and solutions which constitute the construction process. By focusing on the actors and objects involved in successive accommodations, it highlights three distinct modes of decision making which inform the uptake of a system innovation at the level of construction projects.

2. Literature Review

Much construction research looks at sector level and macro level innovation; in contrast, this paper focusses on the challenges at the project team level by exploring accommodations to both the innovation and its context as the innovation is implemented. In doing so the paper rejects the notion of linear models of innovation and uptake (Rothwell 1994) and the distinctions between invention, innovation and uptake (Rogers et al. 2001).

A number of papers developed the idea that the effect of innovations varies with the local context. In a well-known typology, Henderson and Clark (1990) distinguished between four types of innovation, based on the relation of the innovation to the firm and its processes; These include: architectural, modular, incremental and radical innovation. Whereas Henderson and Clark focused on the effect of discrete innovations, Slaughter (1998) explored the impact of innovations which are more systemic in nature. Her research classified innovations by their distance from current practice, and their links to other components and systems. She distinguished between the discrete types of innovation outlined by Henderson and those which have system characteristics and which therefore require coordination among the project team, special resources and greater levels of supervisory activity. In a parallel study, DuBois and Gadde (2002) contrasted different types of construction contexts. Their largely conceptual paper distinguished between tight and loosely coupled systems to explain differences in the accommodation of innovations at both project and the firm level. The discussion which follows builds on these arguments concerning variations in the effect of innovations on the local context, be it the building design or the processes through which it is developed and argues for the need to explore empirically the process of accommodation within the project.

The relatively more recent advent of micro level socio-technical studies has contributed significantly to our understanding of innovation implementation in construction. Both Kjellberg (2010) and Harty (2008) used ANT to explore the introduction of innovations at the project level. In a study of the introduction of 3D-CAD software, Harty introduced the concept of relative boundedness to highlight the way in which innovations often have spill-over effects which go far beyond those intended or even anticipated. Harty's study also pointed to variations in actors understanding and thus use of a similar technology. This paper draws on both points, as it explores differences in key actors' motivation for adopting BIPV, their effect on design decisions and their unintended consequences.

An aspect of this problematic can be found in Kjellberg's (2010) study of the impact of a process innovation on the transformation of a warehouse. In his paper, Kjellberg documented the effect of a new warehousing system on both innovation and building design decisions. While, Kjellberg's study focuses on the transformation through implementation of a management system, his argument can be applied to the study of technical, systemic innovations. The research presented below explores the effect of BIPV on the ongoing design of the commercial building into which it was incorporated.

The analysis which follows contributes to these micro-level explorations of the accommodation of building project teams and building designs to the demands of new innovations. In contrast to these studies, the study of BIPV pushes the general argument one step further by problematizing both the design of the technology and the building. It also provides a basis to reflect on different modes of decision making, thus contributing to current understandings of both barriers to uptake and the processes supporting green construction. More specifically, it draws attention to the challenge of integration at the level of decisions.

3. Background

BIPV is a form of photovoltaic technology which is integrated into the fabric of a building. The technology is not fixed in format and in the UK is typically bespoke in design. It consists of several components: the photovoltaic cells which are laminated into the façade/louvre glass, connectors and wiring which take the DC generated electricity from the cell to the invertors, invertors which convert the electricity to AC and an export system which exports surplus generated electricity to the grid. Each of these components have implications for the design of the BIPV and similarly the design of the building will dictate the number of cells used, their configuration, length and location of wiring, position of invertors etc. By considering BIPV as a set of components, it can be considered as a technological assemblage which interfaces with the rest of the building design. Conflicts and resolutions occur as the technology is accommodated within the design and construction of a building. For example, the PV panels are accommodated within the frames of the façade, the wiring has to be concealed within the building and the invertors and metering systems have to fit within both the building and the electrical arrangements of the building.

4. Research approach and method

4.1 Analysis

Social Construction of Technology (SCOT) adopts a socio-technical approach to technological development. Analysis focuses on the networks of actors and objects which form around the specification of problems and solutions in the development of a new technology or, in this case, in the implementation of BIPV into a building (Bijker 2009; Schweber & Harty 2010).

For the purposes of this paper, the approach allows for consideration of the way in which construction professionals deal with problems and their resolution without privileging or distinguishing between types of issues (technical, design or management). It also draws attention to different motivations or criteria for discrete decisions. Although SCOT usually focuses on the development of a single technology, this paper extends the approach to explore the co-development of BIPV and the building in which it is introduced.

The case study, Future Green, is a commercial science centre which incorporates BIPV into the windows to meet its carbon reduction goals. It is one of three case studies in a larger research project; it was selected for this paper because of the very visible and unintended consequences

which the introduction of BIPV had for the appearance of the building. Data collection combined semi structured interviews and document analysis. The project was identified by the supplier of the PV panels and contact was first made with the project architect. Snowballing was used to identify participants, until no new project members were identified. In total 13 construction professionals were interviewed. The research received ethics approval from the University of Reading and was carried out in line with these requirements.

Thematic analysis using NVivo 10 focussed on identifying problems and solutions arising during the project. In addition, attention was paid to the range of different considerations which led to particular decisions and their impact on the co-development of the building and the BIPV technology. Diagrams to explore the sequence of problem and solutions throughout the build were drawn up and problem solving strategies were identified.

As a method, SCOT provides a basis to explore discrete decisions and their effect on the development of a technology; however, it is less good at identifying the effect of broader structural characteristics which shape the process (Klein & Kleinman 2002). In the case study discussed below, the use of SCOT may have obscured issues of project organisation, path dependencies or management styles, which indirectly influenced particular decisions.

5. Future Green

The case study, Future Green, is a commercial science hub which is the first stage of a mixed development which includes the science hub, commercial offices, retail outlets and residential housing. The client group included a university and a city council, along with several other strategic partners. Future Green is a seven floor mixed space building, including exhibition and office space. Occupants, renting the offices are expected to be start-up businesses within the field of sustainability. Although predominantly council owned and run the building is operated by a private company which is in charge of letting space and running the building.

The project started out as a flagship sustainability project and BIPV was used to support this statement. BIPV panels were incorporated into ten of the 12 windows on the south-west elevation of the building. Other sustainable features included a small solar thermal installation on the roof of the building, a green roof and green wall on the west elevation and natural ventilation on the upper floors. The building includes many irregularly spaced, tall, narrow windows which make a bold architectural statement against gold cladding and green vertical brise-soleil panels. The project was carried out under a design and build contract.

The analysis which follows describes the co-development of the BIPV panels and the building, from the perspective of key design decisions and the socio-technical network which supported them. Figure 1 provides an overview of the process of co-development; while Figures 2-5 present enlarged (more legible) sections of the diagram to support the discussion. Each shaded box represents a decision or action which shaped either the building (the top line of boxes) or the BIPV (the bottom line). The unshaded boxes mark key points in the co-development story.

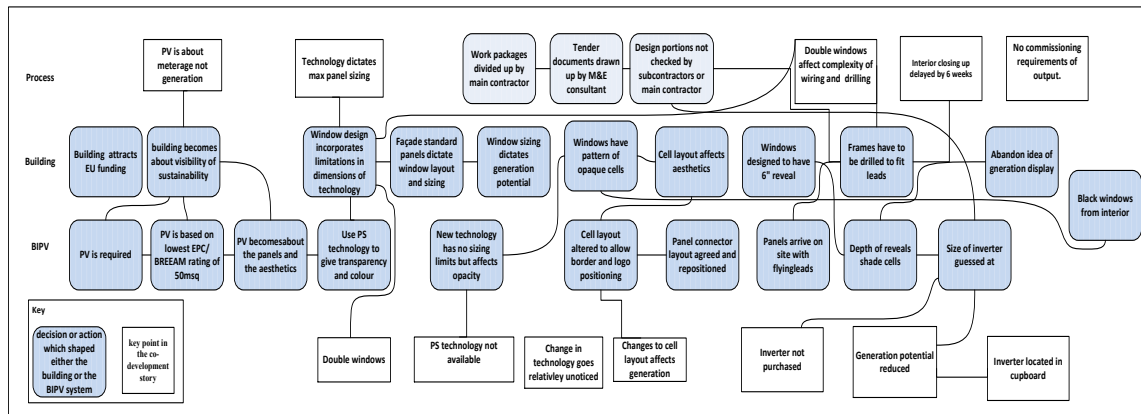


Figure 1 Co-development of BIPV and Building:

As Figure 1 indicates, the integration of BIPV is analysed as a succession of problems and solutions which led to the integration of BIPV within the window panes as a distinctive element of the glazing. Far from a simple decision, discussions around this feature passed through phases, each of which involved a slightly different problem and associated set of actors, objects and considerations. In the early stages, the architect proposed the use of thin film PV technology. During the tender phase, procurement problems led to their replacement with conventional monocrystalline cells, but knock-on effects on frame design and glazing beads were not picked up until well into construction, resulting in delays and re-work. The discussion which follows traces this decision making process.

5.1 Choice of technology

The introduction of BIPV was initially informed by the clients' early decision to attract European Regional Development Funding (ERDF)¹. Conditions for the funding included the achievement of a BREEAM Excellent and preferably BREEAM Outstanding rating as well as an Energy Performance Certificate (EPC) rating of at least B and preferably A. Both A and B EPC ratings required the use of renewable technology.

Early on in the project, the client, architect and lead mechanical building services designer held a review of the sustainability options with a view to selecting which technologies to use. The architect and client were intent on using highly visible forms of sustainable technology so that future tenants and the general public would see that the building was green; they favoured the use of green walls and roof and solar technology (both solar thermal for hot water and photovoltaics (PV) for electricity generation). The design team considered using a conventional roof mounted PV system, but realised that the green roof would shade the panels. Instead, they suggested mounting them above the roof parapet, but this was rejected as it would not have been acceptable to the planners. In addition the PV panel frames would have had to be fixed to the roof, which would have necessitated piercing the green roof membrane and would have

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https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/9455/National_ERDF_hanbook.pdf (INCORRECT REFERENCE)

threatened water tightness. There was room for a small solar thermal installation on a separate part of the roof, but the space available was small and incompatible with a roof mounted PV system. Following these reflections the team decided to use BIPV.

Under the initial proposal the building with BIPV was set to achieve BREEAM Excellent and B for its EPC rating. For the reasons stated above, the client wanted an A rating and thus asked the mechanical engineer to come up with a design solution. He found that while only 50 square meters of PV panels were required for a B rating, 260 square meters would be needed for the desired A result. The client decided that a B rating would be acceptable, but still wanted BIPV as part of the project.

The choice of BIPV product and its positioning resulted from a succession of considerations. The architect wanted to incorporate BIPV on the large south-east elevation which was visible from the street. After looking at the building layout and the layout and positioning of brise-soleil louvres on the south east, the mechanical design engineer advised against this option as the façade had already been designed with large vertical brise-soleil louvres which would have shaded the panels and reduced efficiency. The two professionals considered incorporating the PV into the brise soleil louvres, but rejected this on cost grounds and eventually settled on using BIPV in the windows of the south-west elevation which had no brise-soleil louvres. The architect decided to specify thin film PV technology which, despite being of a lower efficiency than conventional monocrystalline technology, would give some transparency to the windows and also allow the windows to be coloured bark brown and so add to the sense of drama.

As indicated above, the decision to include a BIPV system was driven by the client’s desire for a building with a strong sustainability statement, the planners’ concern for energy generation and an appreciation of the interdependence of different components of BIPV and the building. Figure 2 shows how the bid for EU funding and the client’s wish to make a strong visible sustainability statement drove the inclusion of BIPV on the project, which then moved the frame through which the actors viewed the technology from one of electricity generation to one of visibility. This drew the architect and designers to using BIPV in the windows and so made the choice of thin film technology desirable. Decision making was thus driven by a dialogue between different actors, with different motivations. All of the actors involved were aware of the range of different considerations and the negotiations supported a well considered decision, taking into account the systemic properties of the technology and the building design.

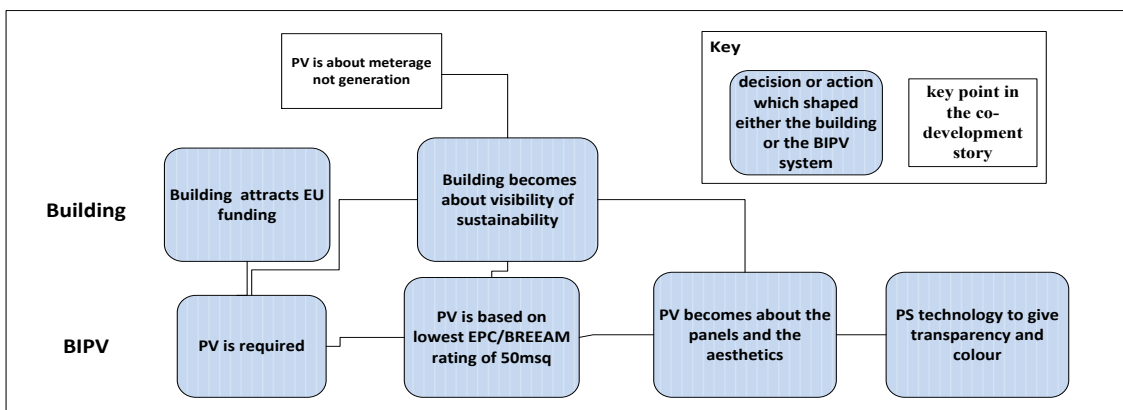


Figure 2: Choice of technology

5.2 Allocation of work packages

The process of developing tender packages for the project was also problematic. The project team continued to design the building, with the mechanical design engineers and architect developing the technical specifications and the main contractor deciding how the contracts for tender were to be allocated. When dividing up the work packages for tender the main contractor decided to include the BIPV panels in the envelope tender package and all the other parts of the BIPV system in the mechanical and electrical package for the internal work of the building. In doing so, he privileged conventional building practice over the technical requirements of the technology.

It made perfect to put it into the envelope package, because it's no different to installing any other window, it's just got the PV components within it.

Main Contractor

The M&E design consultants drew up the tender packages accordingly and included substantial design portions in each tender package for development of the design for the configuration of connections on the panels, location and sizing of the inverters and wiring from the panels to the inverters. The consultant was very clear that further integrated design between the M&E contractor and the façade supplier would be necessary to make the technology work.

They have to liaise quite closely with the architect over the installation details, because it would ultimately be part of the façade installation, the two would have to come together and form an integrated solution.

Mechanical Design Engineer

The packages went out to tender and were duly awarded. The main contractor was not aware of the requirement for detail design of the system and the contractors had not read the detail of the specification. The façade supplier viewed the PV panels as just another sort of glazing panel and this resulted in the PV panels arriving on site with two flying leads on each panel and no plan about how they were to be incorporated into the façade and penetrate the building. Some windows were mounted one above the other and this double height design made the installation even more difficult. At the same time the M&E contractor had neglected to plan how the wiring was to run from the frames and had forgotten to order the inverters. Figure 3 shows how this progressive lack of integration and design led to a delay of the internal finishing of that elevation of the building of six weeks.

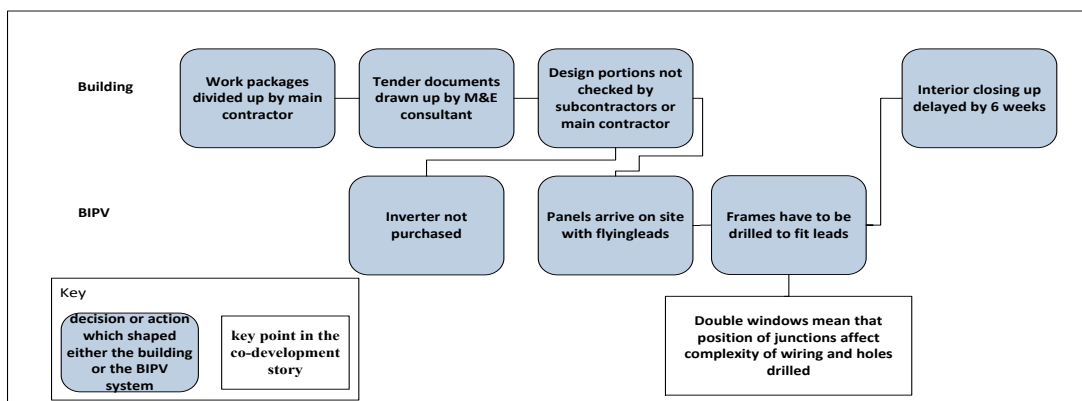


Figure 3: Allocation of work packages

5.3 Change of technology

During the tender phase, the thin film technology was replaced by conventional crystalline cells as the original system proved to be unobtainable. As the discussion which follows and figure 4 indicates, the architect made this decision based wholly on aesthetic considerations, with no consideration for the knock-on effects of his decision. It was only well into construction that the effect of using the more conventional monocrystalline cells on frame design and glazing beads were picked up, resulting in delays and re-work. In the end, BIPV contributed to a strong visual statement from the outside, coupled with a significant loss of functionality from the inside. The BIPV windows were opaque, reducing visibility, and their energy generation was extremely low. The exterior of the finished building clearly showed the inclusion of BIPV in the windows, but internally this was translated into a loss of functionality – both in terms of the transparency of the windows and in the very low PV generation. An account of the substitution of the BIPV product explains how this less than optimal outcome happened.

When BIPV was first suggested, the architect and engineers opted for a thin film technology on both functional and aesthetic grounds. As the architect explained, the brown colour of the panels would resemble wood bark and contrast with the gold façade while the translucent finish would provide light through the windows. The thin film technology had limitations in terms of the dimensions that could be manufactured; this meant that most of the PV windows would be made from two panels, one above the other. In addition, the standard glazing panel sizing for non PV windows dictated the window layout and sizing.

During the tender process the thin film technology became unobtainable and the supplier proposed to substitute it with conventional monocrystalline PV panels which would provide slightly superior PV generation, but which were not transparent. Transparency would be provided by the spacing between the PV cells, rather than as a general translucency across the whole panel. The architect and main contractor were keen to keep to the schedule and agreed that the new technology be used. The architect worked with the glazing supplier to optimise the layout of the cells and logo to have an even border and symmetrical cell spacings. The architect was unfamiliar with the differences in the two technologies and summed up the situation:

The only difference as far as I know with that is it's the graphical display of the cells... the original specification that we had was more of a bark wood type. ... it wasn't a massive issue, we just went back to an alternative specification.

Architect

The knock on effects of this decision was that the changes to cell spacing affected the generation potential of the technology and the aesthetics of the windows from the inside. Instead of a semi-transparent brown wash, up to 80 % of each PV window now had blocks of black opaque cells. The other thing to pass without notice was that the restriction on the dimensions of the technology no longer applied, such that the windows could have been specified as one panel, thus reducing the number of joins and flying leads.

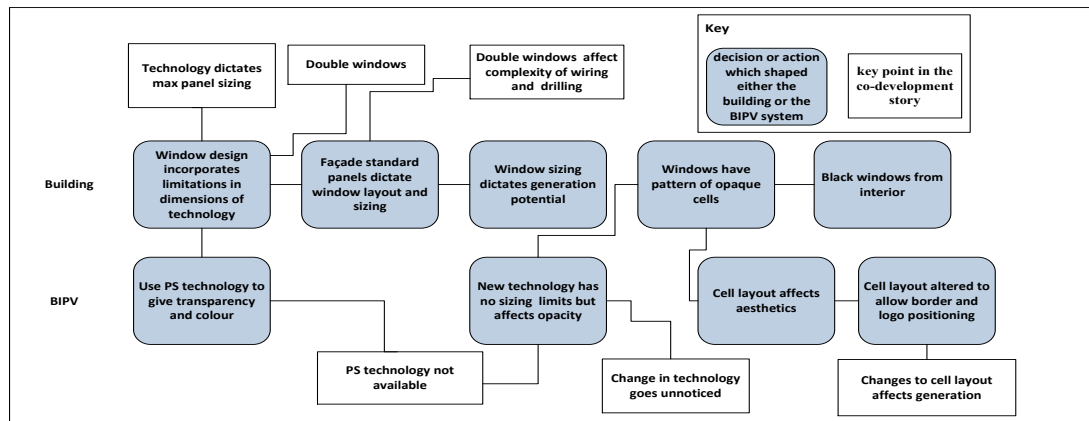


Figure 4: Co-development of building and BIPV

During the construction phase the lack of design and coordination of the BIPV system led to rapid discrete decisions being taken over frame modifications, glazing beads and wiring configurations. These decisions sub-optimised the output potential of the system and resulted in delays and re-work. In addition, an aesthetic detail for deep window-reveals resulted in shadowing of the PV cells during significant periods of the day which dramatically reduced generation further.

6. Discussion: Modes of decision making

Over the course of the project a series (and sometimes parallel set) of problems and solutions led to the co-development of the building and the BIPV. Finally, the incorporation of BIPV into the building reduced internal visibility and resulted lowered PV generation, effectively transforming BIPV from a renewable technology to an external sustainability statement.

Reflecting on how this happened, the succession of problems and solutions discussed above point to three distinct modes of decision making, including: discrete decision making, conventional decision making and integrated decision making.

Discrete decision making occurs when decisions are taken in isolation without reference to the rest of the project. In this mode, decisions are made based on the immediate situation, where immediacy refers to both the spatial and temporal dimensions. In the decision over the choice of technology, the architect addressed the issue based on his aesthetic concerns. He selected the thin film technology because it gave a semi-transparent window and because its brown colour added to the sustainable look of the building. When the technology was no longer available from the original supplier, he agreed to substitute it with monocrystalline cells, without considering that the PV technology was only one part of the larger BIPV system. As the discussion above indicates, this discrete decision had a number of knock on effects. Not only was the generation capacity reduced, but the windows became opaque. Collateral damage also occurred when original size limitations on the windows no longer applied, but were kept in the design, thus complicating wiring configurations and when the size of glazing beads needed were not altered to fit the new, thicker panels.

The term ‘conventional decision making’ refers to decisions based on standard procedures. Unlike discrete decision making, this mode takes into account broader temporal and spatial considerations, but not the specificity of the technology and the building. Like discrete decision making, this mode fails to take into account the knock on effects of the changes to components of the technical innovation. In the case of Future Green, this mode is evidenced in decisions around the procurement of technical components and the division of labour into work packages.

As the discussion above indicates, the main contractor divided up the tender work packages based on the conventional division between the envelope package and the internal mechanical and electrical fixing work. The M&E consultant was asked to draw up the work packages and allocated design portions within the packages. The result was that the visible aspects of BIPV were included in the envelope package, whilst the hidden part of the BIPV (the electrical part) was buried within the M&E package, where the design portion including sizing and procurement of the inverter was forgotten. Not only were the electrical components forgotten, but, also, the interfaces between the glazing units, the frames and the internal wiring were not considered until installation; consequent problems took six weeks to resolve.

The third mode identified in this study is integrated decision making. This involves collective consideration of the system properties of both BIPV and the building and is illustrated in the development of the initial bid for EDRF funding. In preparing the bid, the client, architect and M&E designer looked into the implications of using different forms of sustainable technology. They clarified the implications of installing a green roof and of using solar thermal installations and, based on these considerations, agreed to use BIPV on the façade instead of roof mounted PV panels. The decision to use BIPV in the windows was made once the requirements for an EPC rating of B were understood and the square meterage of PV matched the window sizing. The south west elevation was chosen for the BIPV as the implications of using the south east façade with its brise soleil panels and consequent shading was unsuitable. All the team members were in agreement that BIPV windows were the preferred solution and understood that from that point the BIPV was primarily about making an external sustainability statement, rather than making a contribution to energy generation.

A second example of the integrated mode can be found in a coordinated response by multiple project team members to on-site problems. This type of flexible, local problem solving is widely recognised as a strength of the sector. In the case of Future Green, the conventional decision to separate the procurement of BIPV into mechanical and electrical packages and the subsequent isolation of the PV glazing from the frame led to a series of on-site issues ranging from how to incorporate the flying leads into the frame and take them inside the building to how to complete the weatherproofing of the envelope when the PV glazing beads were the wrong size. As the different subcontractors were brought together by the main contractor, an integrated decision mode was developed which allowed for innovative solutions to be found.

By analysing the use of these three decision making modes across the implementation process, it becomes easier to understand how and why problems arose in the incorporation of BIPV and why the project failed to deliver on its initial aims. Far from being unique to this project, the

argument is that these dynamics are characteristic of innovation in the construction sector. In the case of Future Green, the integrated mode used at the beginning of the project allowed the team to focus on the issue of sustainability as a whole. This led to a holistic solution with clear specifications for the proposed BIPV system. When the thin film PV technology proved to be unavailable, the architect adopted a discrete decision making mode and agreed to the substitution of monocrystalline cell technology, without linking the decision back to issues of generation or functionality which stemmed from this decision. The main contractor's use of the conventional decision mode in deciding work package allocations set the scene for a fragmented development of the BIPV system and a series of problems at the interfaces of both the BIPV system and the contractors on site. Integrated decision making helped to address the local issues on site and encouraged some innovative problem solving, but it could not impact the effect of earlier discrete and conventional decision taking which locked in an opaque windows and low generation outputs from an early stage for the project. The "crown jewels" were indeed installed in an eye-catching setting, but despite good intentions, proved to be hollow when viewed from a point of functionality and value.

7. Concluding Comments

In closing it seems incumbent to return to the initial research problem and ask what this analysis contributes to an understanding of technical innovation in general and sustainable innovation in particular. On one level, it documents the complexity of the decision making process and the co-development of system technologies and buildings. On another level, the distinction between modes of decision making provides the basis for a more nuanced understanding of how 'integration' might address the challenge of sustainable construction.

Whereas most scholars focus on the integration of project teams, this study suggests that formal managerial changes are far from adequate. Sustainable construction depends on a shift in the mode of decision making from discrete and conventional decisions which, while they have the benefit of efficiency, threaten to undermine client and project goals for the new technology.

The challenge is for project teams to recognise the interfaces of the technology and identify which mode of decision making is most appropriate. In the study of innovation and uptake this raises the question: "under what condition do teams engage with an integrated mode of decision making and what can be done to encourage it?" It also raises the issue of the role of contracts and formal structures and procedures in promoting conventional decision modes rather than integrated ones.

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Requirements compliance checking for existing buildings

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Abstract

Most of the building stock in Europe has been built in the sixties and nowadays it is not always fulfilling current requirements coming from binding laws, voluntary standards and clients' needs. When dealing with assets acquisition or with decisions on their reuse and refurbishment, it always takes a big effort just to understand if a building complies with current regulations, because of the lack of knowledge and laws complexity and jeopardising. This paper shows a tool able to help users dealing with the requirements compliance checking of existing buildings. The purpose of this tool is to enable decision makers in making strategic choices about their assets, by providing them the actual state of the building regarding the requirements compliance. The tool consists in a set of checklists, tailored for building function and declined in all the possible type of spaces of the building; this because each space has specific requirements to fulfil, as well as the building itself (intended as an entity). The tool uses as an input spaces dimensions, performances, characteristics but also documents and permissions; with a calculation procedure, it gives to the user a set of data. This kind of check is fundamental to take decisions about how to conduct the asset: refurbishment, handover, retrofit or simply maintenance are all options that can be evaluated only with the correct knowledge of the asset. A preliminary case study is presented here just to show the potential of this tool; to improve the compliance checking process, some characteristics (that can be automatically checked) have been implemented in Solibri Model Checker. The remaining have been checked manually with other software and all the results have been collected in the checklist developed. This tool is part of a bigger work that wants to look not only at the requirements but also at the physical state of the building (so to organise maintenance), the energetic behaviour (so to optimise consumptions) and at the adaptability potential (so to evaluate functional change alternatives).

Keywords: Asset management, requirements compliance, real estate, BIM, IFC

1. Introduction

Most of the time, especially for new constructions, checking available documents is sufficient to provide a clear situation of the compliance with laws and standards of the building under analysis. But dealing with the real estate means to face modifications occurred over years, missing and not updated documents, compliance with new standards and in general with a lack of information (Montague, 2015). This is the reason why most of the times it is necessary to review the response of the building and its spaces to mandatory and even voluntary requirements, given by either laws, regulations, standards, guidelines, clients and owners.

Therefore, it is necessary to go beyond the analysis of pathologies, service life and documents: it is necessary to provide users with a clear framework of the building compliance to requirements, divided by function (both of the building and of each single space inside it). So the objective is to create a checklist, easy to fill (no need of professionals for most of the controls), able to return to the user a clear understanding of the building, to allow, if need be, planning restoration and adjustment works.

This is also strictly related to building adaptability (Kelly *et al.*, 2011): as adaptability is the ability to accommodate changes, requirements fulfilment is a pre-requisite, necessary to allow these changes. An example is given by building functional change: a building may change its function more than once during its useful service life (Kincaid, 2000), but, even if it is technically possible, maybe the adaptation is not allowed. So this type of check completes the adaptability assessment, giving to users the possibility to plan operations not only to restore defects and pathologies, but also to restore the compliance with binding laws. Compliance checking can be also performed during the handover, both by the seller as a guarantee and by the buyer as a control.

This paper shows, after a brief state of the art related to regulatory compliance and code checking, the tool developed by the authors, with the help of a case study (an existing office building). The paper contains also a short explanation of the assessment and calculation procedure of the tool and the discussion about results generalisation and limitations.

2. State of the art

Here it is a brief description of the state of the art related to regulatory compliance in general and to code checking with automated (or semi-automated) software, in connection with BIM models. Even if using a BIM model to perform this kind of checking is not mandatory, project complexity is become so critical that needs to be handled with dedicated software.

2.1 Regulatory compliance

Regulatory compliance checking is an activity done mainly during design stages, with an increasing complexity from the brief to the final design stages; this checking is made also after construction, to check the compliance between what has been designed and then built. In a

perfect world, all these data about requirements can be easily checked in the documents or directly in the building, but with the Italian real estate, built mainly in the sixties with different laws and standards, performing this check is not an easy task.

The due diligence, defined in the ISO 26000:2010 as the “*comprehensive, proactive process to identify the actual and potential negative social, environmental and economic impacts of an organization's decisions and activities over the entire life cycle of a project or organizational activity, with the aim of avoiding and mitigating negative impacts*” can be the solution to the problem. Due diligence can have wider objectives, allowing to assess several aspects of a building through an audit (defined as a data gathering procedure); also Building Condition Assessment (Re Cecconi *et al.*, 2014) can be considered a technical due diligence, as the regulatory compliance checking.

Even if this assessment spaces on a really wide range of topics (fire fighting, safety, accessibility, comfort, etc.), the evaluation process is quite straightforward and simple: a complex assessment system with weights, categories and tools is not mandatory to perform a good check; nevertheless, the complexity of the laws and standards frameworks is pushing the need of software able to automate these checking, which now imply a huge effort for designers (Malsane *et al.*, 2015). On the opposite, there is the need to pay great attention to the requirements to be checked: a requirements database must be provided, so to have the possibility to check their fulfilment, space by space and for the entire building. Even if not related to buildings, an interesting example is given by Maxwell and Anton (2009), which provided an assessment system dedicated to a health record system, able to check the requirements against the current U.S. law.

Requirements can be associated to the part of the building they are related to: building (as a whole), spaces and components (including subcomponents). Building (as an entity) has to be considered in relation with surroundings (other buildings, landscape, viability, etc.), but also some characteristics have to be checked on the whole building (number of exits, height, extension, etc.). Spaces are really important for requirements compliance: most of the times the function of the space influences the requirements, so a careful space-checking must be done. Components must have some characteristics depending on the building/space function, but some requirements are also connected to single layers (especially finishing, load-bearing elements, insulations, etc.), even if they can be easily transposed to spaces. Eventually, to perform a proper requirements due diligence, many aspects must be checked, some of them can be generalised, but many others must be checked depending on the specific building.

Requirements fulfilment, together with a price list, maybe appositely implemented, can provide to the client and to decision makers the clear situation of the money to be paid to restore the building compliance, if need be, or to change the function of one or more spaces, which is a frequent activity, especially in offices and commercial assets (Kincaid, 2000).

2.2 Code checking

Going further with this topic, together with the requirements database, a tool to automatically check them should be provided: this because buildings complexity is always increasing and doing this check manually is becoming more and more hard-working. A solution to this problem can be given by Building Information Modeling (BIM) that, together with the IFC protocol (BuildingSmart, 2015), provides an instrument to ease these kinds of controls. Maxwell and Anton (2013) provided a demonstration of the potential of the code checking procedures, by applying them to a water distribution system. Malsane *et al.* (2015) tried to translate (and optimise) the rules related to fire safety for dwelling houses in England from textual rules into computer-readable rules; as can be seen from their work, the code checking is not only a matter of using a software, but the comprehension of the rules (and the consequent transposition) is very important. This leads to the need of having a proper database of regulatory requirements to be used, not depending on the automated compliance checking tool to be used.

Despite the importance of BIM code checking, Cao *et al.* (2015), by analysing 106 BIM projects in China, state that BIM is used mainly for design (fabric and services), clash detection (during construction stage) and not too much for checking the design against building codes. Anyway the interest on BIM is constantly increasing (Market Research Reports Inc., 2015), so also this task will be soon more important.

Code checking can be performed also as an audit connected to Facility Management (Dimyadi *et al.*, 2015); authors presented methods commonly used to represent and access digital regulatory knowledge for compliance audit purposes and claimed for an open standard regulatory knowledge representation.

Solibri Model Checker (SMC – Solibri, 2015), one of the most famous instruments to performs these checks, can be given a set of rules to be applied to the building under analysis, so to check requirements and create a report (Solihin and Eastman, 2015). Also regarding BIM technologies and code checking, Dimyadi and Amor (2013a and 2013b) and Dimyadi *et al.* (2014) provided interesting data.

Not all the requirements can be easily automatically checked. As instance SMC does not make calculations, which are frequently asked during regulatory compliance checking. This is way the first part of this research focused on the definition of the requirements in a clear and comprehensible way, not related to the tool to be used to perform the check.

3. Information management

The assessment of requirements fulfilment (by law, voluntary, by the client – related to the whole building and to each single space) is a direct consequence of the current state analysis of pathologies and documents, as it completes the building picture. Requirements analysis, guided by a set of sheets and a procedure, is fundamental to understand if the building, not depending

to the documents describing it, respects the laws and fulfils the function it is designed for. This analysis includes the control of:

- a) requirements of each single space of the building;
- b) distance among/from spaces;
- c) requirements of the building as a whole;
- d) distances among/from the building and other buildings and surroundings.

It is important to notice that requirements have been collected in a database for each single building function, i.e.: office, commerce, cinema, catering, school, etc.; in this way a detailed list of requirements has been obtained, updated to the law in force and attributable to each single (fundamental) space for each function.

This instrument can be used both during the design, as a checklist to control requirements fulfilment, and during use, to check their fulfilment in course of time. In addition to these two main uses, it can be an important instrument to verify the function change, even of only a part of the asset, to assess the compliance to new requirements, as it makes available the reference regulatory framework, with the related operations necessary for the refurbishment; costs can be associated to these operations, allowing to assess in a complete way the opportunity of a functional change. An assessment of this kind has several applications regard safety issues, both regarding the whole building and the activities inside.

Requirements compliance is an important theme, especially if an entire portfolio is considered: through the spaces use and the compliance of their requirements it is possible to plan modifications and so the budget for adaptation works (possibly in connection with other maintenance works).

A future development of this system is given by the possibility to assess the efficiency in space use: it is sufficient to think about how many spaces are not adequately capitalised; having the complete picture of the spaces could help in managing them at their best, avoiding waste and consequently missed incomes. The index under development can help in different situations:

- a) to provide the requirements compliance situation of the portfolio, asset by asset: define the operations to be done to restore the portfolio requirements compliance;
- b) to provide the requirements compliance situation of the asset, with the list of missing requirements: define the operations to be done to restore the asset requirements compliance, category by category;
- c) collect professionals and operators to act properly.

4. Requirements index

Regulatory compliance checking is part of a broader condition assessment tool, involving physical (pathologies, ageing), adaptability and documents checking. Nevertheless, this part can be also used as a stand-alone assessment system. This study is now focused on tertiary office buildings, but other functions (food services, hospitals, residential, hotels, etc.) are under analysis. Buildings dedicated to tertiary activities (offices in this specific case) have been firstly analysed to get the complete list of possible spaces and zones involved (i.e. from Neufert,

2013), then a requirements list, space by space (and for the whole building) has been created starting from current Italian laws and standards. The process of this checking consists of four main steps (Figure 1):

- a) Survey of the physical asset, made of the asset itself and a series of documents and drawings;
- b) Creation of the digital asset, consisting of a Common Data Environment (CDE), in which information are stored in BIM models and digital documents;
- c) Checking of the requirements compliance with current standards, laws and client's needs. This is done automatically (e.g. with Solibri Model Checker) or manually (when an addition data elaboration is needed);
- d) Reporting of the situation and, if need be, restoration of noncompliances.

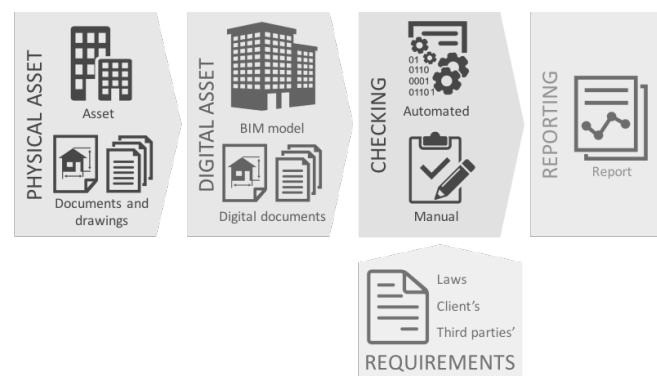


Figure 1: Scheme of the process

4.1 Requirements database

To create a metric for space requirements compliance checking, a database with a precise set of requirements is needed. This should be done incrementally: a complete set of requirements for all spaces and building functions is hardly achievable in a short term. But a robust framework can be designed to gradually collect data in an efficient and effective way. This database is only the aseptic collection of requirements, which should be declined for each specific building under assessment. Each requirement is connected to a specific space and building function (remembering that many spaces can belong to different buildings functions). Each space should be unequivocally defined (e.g. an office with less than 5 people may be different from an open space office with more than 20 people). Here it is the list of data that should be gathered:

- a) object of the control: short name of the parameter to be checked (e.g. minimum floor area, maximum number of people, etc.);
- b) condition of requirement satisfaction (e.g. minor than, equal to, greater than, etc.);
- c) threshold value;
- d) internal threshold value, given by the client, to be considered valid only if more restrictive than the threshold value given by law or voluntary standard;
- e) unit of measure of the threshold value;
- f) source/reference of the requirement, split in three types (each category is associated with a weight): binding law, client's need and voluntary standard;

- g) type of control (this leads to different data to be checked and inserted by the operator to verify requirements compliance): visual, documents, calculation, distance and connections;
- h) building type: existing building, new construction or both;
- i) measuring criteria, the precise definition of how to measure the parameter to check requirement compliance.

In Figure 2 there is an extract of the database created.

Requisito	Figura del controllo	Substruttura spaziale	Condizione	Valore di soglia	Unità di misura	Dimensione parametro	Struttura di riferimento	Tipologia di controllo	Criterio di calcolo	Nota	Valore di soglia	Unità di misura
REQUIREMENT												
MEASURING CRITERIA												
REFERENCE												
CALCULATION PROCEDURE												

Figure 2: Extract of the requirements database for office buildings

Totally 236 requirements have been collected and associated to 9 major spaces and to the whole building; most of them are the same for many spaces, so the total number of requirements could be reduced to a handier number, if considering that they partially overlap in many spaces. 15 documents (standards and laws) related to office buildings have been checked to provide this list of requirements.

4.2 Space level

The space level is the first level of calculation of the requirements compliance. In this step the requirements database is connected to a specific building and to specific spaces inside it. The data listed above remain the same (they cannot be modified) and additional information must be added. Here it is the list of additional parameters to be filled, once selected the specific space:

- a) space data, necessary to unequivocally identify it: number, name, code, space function, space typology, space net floor area, space gross floor area, measured value, document reference, requirement compliance: Y – Yes, this space requirement is fulfilled, N – No, this space requirement is not fulfilled, NC – Not Checked, this space requirement has not been checked and NA – Not Applicable, this space requirement is not applicable to this specific space;
- b) adaptation, the need of adapting the space to fulfil actual and future requirements.

After the completion of all the relevant data, for each space, some indexes and key information can be calculated automatically, to define the space requirements compliance. Here the main steps to be done are reported:

- each requirement, depending on its source/reference, has a weight (to be fine tuned with one or more case studies): 0.6 for binding law requirements, 0.3 for client's need requirements and 0.1 for voluntary requirements;
- the weighted sum of all requirements (from 1 to n) needed is the maximum weighted Space Requirements Index;
- the weighted sum of all requirements (from 1 to n) compliances is the current weighted Space Requirements Index;
- the weighted Space Requirements Index is the ratio between the maximum and the current situation;
- as the only index may be not enough to understand requirements compliance, other statistics can be extracted.

Eventually, a graphical representation of the results is a good way to understand each space situation at a glance. The red part of the Figure 3 shows the remaining score to achieve the sufficiency, given by the lack of compliance to binding law requirements.

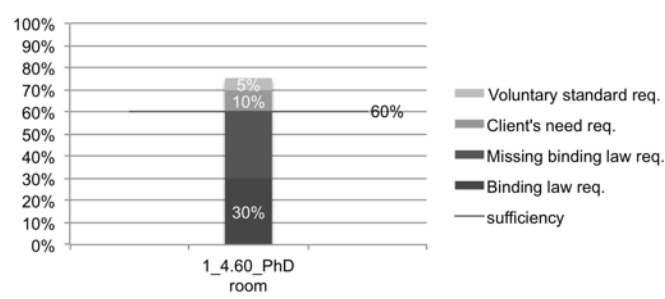


Figure 3: Example of output of the Space Requirements Index

4.3 Spatial unit level

A spatial unit is the collection of all the spaces with the same function. At this level no data are required to be filled by the surveyor. This level is fundamental for understanding building behaviour but there is the need to converge to a single result (or a small set of data); so it is explained the decision of keeping as many data as possible at the space level, using functional units and building levels only for calculations. For each function, the weighted Spatial Unit Requirements Index can be calculated as the weighted summation of the index of each space, using the the net area as a weight, which allows to consider the economic importance of the space, as it is related to the unitary cost; in addition, it is easily quantifiable and objective. Also at this level, interesting statistics about the regulatory compliance can be extracted from the assessment model. Also in this case it is possible to associate the index with a graphical output.

4.4 Building level

This is the last level of calculation of the requirements compliance index. The weighted Building Requirements Index can be calculated as the weighted average of the index of each spatial unit, using the net area as a weight, which allows to consider the economic importance of each spatial unit, as it is related to the unitary cost; in addition, it is easily quantifiable and objective. Another possible weight to be applied (instead of the net area) is an importance

weight calculated with the AHP technique. The same statistics done at the functional unit level can be done also at the building level, to fully understand building current requirements compliance situation. Also in this case it is possible to associate the index with a graphical output.

The calculation procedure briefly outlined here is still under analysis and some changes will be applied after testing the it on some case studies. In addition to this, one of the best ways to perform a regulatory compliance checking is to create a BIM model (with a BIM authoring tool) and check it with a code checking software (e.g. Solibri Model Checker); this procedure perfectly works for most of the geometrical requirements, while it has some problems with analytic and textual data. Some of these issues and reasoning are reported in the §5, thanks to the application to a case study.

5. Case study

The case study aims to show the procedure and to make some preliminary tests. The objective is to test the regulatory compliance checking tool in combination with SMC. The combination of the checking tool with SMC (manual and automated checking in Figure 1) is necessary, as not the totality of the requirements can be checked with SMC. This case study has to be considered just a first step of this research, which consists of a wider programme, including building condition assessment and adaptability ratings; the final objective is to provide a complete and exhaustive view of an asset and of a portfolio. The building under analysis is an office building of the Politecnico di Milano. It has been built in the sixties as a steel warehouse and then converted into an office around 25 years ago. It has 3 storeys above ground and one under ground. Spaces are mainly dedicated to offices (for both researchers and administration), meeting rooms, rest rooms and connections (corridors, stairwells and lifts). The building has been refurbished in both fabric and services, so there is no urgent need to act to solve problems. The limited number of spaces, spatial units, the availability of data and drawings and the regular shape make this building a good case study to perform a preliminary test. The building is composed by totally 154 spaces, including shared spaces, rest rooms, technical rooms and storages. The BIM model (Figure 4) has been implemented with the following characteristics and components: layers of fabric components, illumination system, HVAC system, fire safety system, lift, fire extinguishers and rooms (with correct name, function, number of people, etc.). The model has been made with the help of eng. Hamir Hakim and Roberto Ferrari using Autodesk Revit.

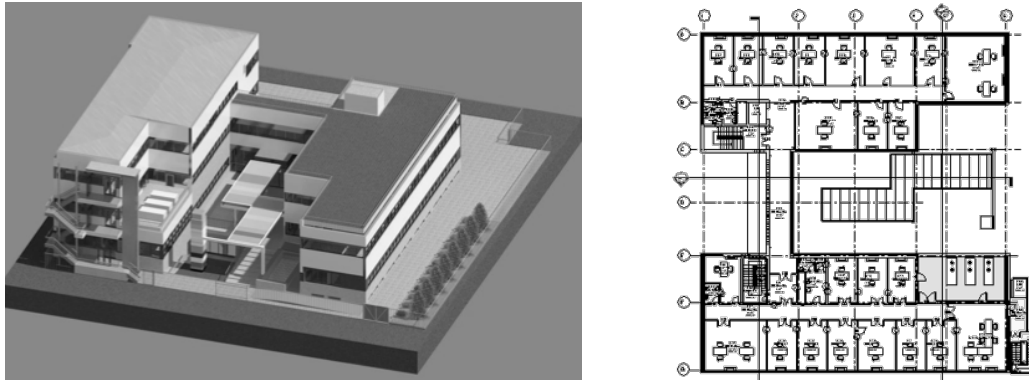


Figure 4: BIM model of the case study (left) and plan of the first floor (right)

The model has been exported from Revit in IFC, allowing to use it in SMC. The coherence of the elements imported in SMC has been checked in the information takeoff section. The requirements have been added to the SMC ruleset, with an explanation and the parameters needed to the check. As said before, it has been possible to add only a part of the requirements (more than 50%) in the ruleset (for the 9 main space categories of the office building), as many requirements were difficult to be managed inside SMC (at least in this first trial). SMC automatically gives a report with the requirements fulfilled or not and the result is that the building presents these issues: some doors (mainly of the rest rooms) have not the minimum width (not for fire safety issues), one door in the under ground opens inside the space and not outside (this issue is related to fire safety) and one office has not the minimum area required (Figure 5).

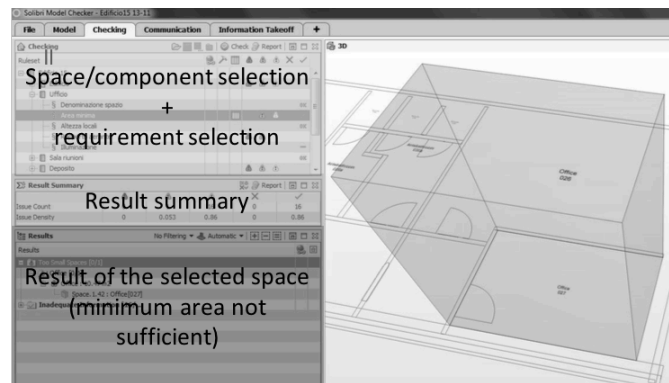


Figure 5: Example of requirement checking in Solibri Model Checker

Some other small issues have been found, e.g. one corridor in the underground has not the minimum width to be considered accessible (but the zone is used as a warehouse at the moment). All the remaining requirements not checked in SMC have been checked within the checking tool, developed in an Excel spreadsheet; among them: permeable surfaces, stairwell typologies, furniture dimensions, finishing fire rating, etc.. Authors are currently working on a way to overcome this issue, so to implement all the requirements (or at least the majority) inside the BIM model, so to fully automate the check. Also the manual checking highlighted some minor noncompliances, among them: some furniture is missing (e.g. dedicated card index cabinets) and there are no data regarding the fire resistance of some finishing (missing data are considered noncompliant). All the results coming from Solibri have been transposed into the Excel checklist (connected to the requirements compliance index of §4), so to calculate the

rating associated and to have a complete view of the criticalities encountered. In general, the building has only few minor issues that can be solved without a great effort; the final rating, for both the whole building and spaces is abundantly above sufficiency (no voluntary requirements have been considered in this analysis). As said before, this case study has only the purpose of outlining the procedure and to show the process of regulatory compliance checking.

6. Discussion

The requirements compliance index has been calculated by analysing all the spaces of the buildings and also the building as a whole (distances from other buildings and distances inside the buildings, e.g. from fire exits). The requirements list was exhaustive and comprehended all the issues to be addressed by these types of controls. The BIM model analysed with SMC greatly helped in cutting the working time to analyse geometrical data, while some issues have been encountered with calculated values (e.g. the window/floor surface ratio). All the requirements checked on the BIM model have been transposed in the tool (in Microsoft Excel), so to have the complete view of the building. There is still a great effort to be paid in developing this tool, starting from a precise procedure to be followed to analyse requirements (which need to be checked in the BIM model and which not). In addition to this, the calculation procedure can be changed and improved according further tests on case studies. Nevertheless, this tool can be easily used by both technicians and asset managers (e.g. without engineering skills). The use of a BIM model and of BIM authoring tools is not mandatory to provide a correct assessment of the regulatory compliance. A possible future development of this tool, once fully defined, is to implement it in a web interface, so to be used online, maybe in connection with an external database and/or the BIM model database; using Revit DBlink it is possible to extract and interact with the database of the BIM model under analysis.

7. Conclusions

Eventually, a great effort still needs to be paid to refine this tool, as at the moment it can be considered just an initial work. The first result is the list of requirements, divided by spaces; this can be used to check requirements during design or handover and even (partially) implemented in a rule set of Solibri Model Checker, so to be automatically checked. The calculation procedure should be revised according to the results of the case studies, which are planned to be assessed in a short future. The second step to be done is to associate costs to restore the compliance with the current binding requirements, so to have a clear appraisal of the expenses to be made; the same has been done with another indicator regarding building degradation and ageing, connected to maintenance, repair and replacement costs over the life cycle. BIM technologies, together with a complete and up-to-date requirements database, could lead to important savings, safer buildings and a better management of portfolios, as the knowledge is the basis of a proper management strategy.

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