

Digital technologies and related competences in construction management in the era of fast-paced digitalisation

Taija Puolitaival,

School of Building Construction, Unitec Institute of Technology, Auckland, New Zealand

(email: tpuolitaival@unitec.ac.nz)

Kathryn Davies,

School of Building Construction, Unitec Institute of Technology, Auckland, New Zealand

(email: kdavies@unitec.ac.nz)

Kalle Kähkönen,

Faculty of Built Environment, Tampere University, Tampere, Finland

(email: kalle.e.kahkonen@tuni.fi)

Abstract

Digitalisation is changing both our personal and our professional lives. This change is continuous and fast-paced. Construction management professionals are required to work smart, using various smart digital technologies during a construction project and to deliver a smart building at the end of the project. To cope with this change from the traditional technologies to digital technologies, continuous competence development is needed and it can be argued that the current mechanisms for this are inadequate to respond to the magnitude and pace of the change. This paper presents part of a larger research project, which has the aim of identifying what digital technology competences a construction management professional requires, and how continuous professional learning can be used to support the professionals in developing these competences. The research as a whole is multi-method qualitative research relying on the constructivist paradigm. A conceptual design framework to support the development of the required competences will be developed and tested. Research methods used will be a combination of literature reviews, document analyses, interviews and focus groups to inform the different stages of the framework development. The research methods used for the current part of the research are systematic literature reviews and document analysis supported by literature reviews. The key terms of ‘digital technology’, ‘construction management’ and ‘competence’ have been defined. A framework consisting of construction management and digital technology functions has been developed to accommodate the construction management-specific digital technologies. The investigation into competences has revealed that basic word processing and spreadsheet skills are the most commonly required digital technology competences and construction management-specific or advanced digital technology competences are very rarely seen as important when employing new staff. The next stage of the research will include further investigation on the competence requirements and on continuous learning methods to address the competence development.

Keywords: competences, competence development, construction management, continuous professional learning, digital technologies

1. Introduction

It is argued that we are currently undergoing the 4th industrial revolution, also called Industry 4.0 or Digital revolution (Roblek, Meško, & Krapež, 2016; Vogel-Heuser & Hess, 2016). There is no unanimous definition of Industry 4.0, but there is a common agreement about the increasing digitisation and digitalisation itself. Applications of Industry 4.0 include robotics, extended reality (virtual, augmented and mixed reality), artificial intelligence (AI), Internet of Things (IoT) and Services (IoS), and Big Data, to name a few. These all are part of advanced digitisation and digitalisation, but the change has been taking place for some time, since the 3rd industrial revolution with automated production in the 1970s, and internet technology a couple of decades later (Lukac, 2015).

Jobs have been disappearing (Degryse, 2016; Ford, 2015) and changing, but new jobs are also emerging as a result of the Digital revolution (Degryse, 2016). Competence development is highlighted in order to cope with the changing scene. Brynjolfsson and McAfee (2011) recommend investment in human capital in addition to organisational innovation. The European Commission has made increasing digital competences one of its priorities, as at the moment “one in every two workers in EU lacks the requisite digital competences” (Degryse, 2016, p. 48). Changes are needed in formal education and also in workplace learning, to reach both the new and the existing workforce.

1.1 Digitalisation in the construction industry

Oesterreich and Teuteberg (2016) carried out a systematic literature review and a case study to investigate Industry 4.0 in the construction industry. They argue that Industry 4.0 has not yet gained much attention in the construction industry, compared to other industries. Oesterreich and Teuteberg (2016) list several main challenges which hinder the investment in research and development, and the change to a more digital environment. These include complexity of projects, uncertainty due to an unpredictable environment, fragmented supply chain with large number of small and medium-size companies with limited investment capability, short-term thinking focusing just on the project in-hand, and strong resistance to change. Despite these challenges, digitalisation is emerging in the construction industry. Building Information Modelling (BIM), cloud computing, mobile computing and modularisation are among the most mature technologies, while others such as additive manufacturing, and robotics are more at the prototype stage, still to be developed for mainstream use (Azhar et al., 2012; Oesterreich and Teuteberg, 2016). From the perspective of a construction management professional, technological change brings continuous change to the processes and the tools used, due to changes in construction technology, manufacturing technology, technology on site and technology for project management and communication.

1.2 Digitalisation and competence requirements

Considering that the Digital revolution has not yet received much attention in the construction industry, it is no surprise that there is little academic literature on the related competences. However, Building Information Modelling, as one of the first digital technologies (DTs) in construction, is also the most investigated area of digitalisation in construction and there have been various initiatives to advance the related competences and competencies. Within higher education, Forsythe, Jupp and Sawhey (2013), MacDonald and Mills (2013), and Wong, Wong and Nadeem (2011) have discussed BIM curricula models. Sacks and Pikas (2013), Succar, Sher and Williams (2013), and Wang and Leite (2014) introduced competency targets and learning outcome frameworks for BIM. On the industry side, at national level Australian Construction Industry Forum and Australasian Procurement and Construction Council released the BIM knowledge and Skills Framework in March 2017 (Australian Construction Industry Forum and Australasian Procurement and Construction Council, 2017). Canada has been working towards a national BIM curriculum since 2014 (Poirier et al., 2016).

BIM Academic Forum (BAF) in the United Kingdom published its first version of a BIM learning outcomes framework in 2013 and the second version in 2015. Very recently, there have been some signs of the discussion shifting from BIM to DT in general (BIM+, 2018). There is no framework available yet for DT competences in construction, and there has not been any wider discussion regarding how to address the necessary competence development. There has been also very little if any discussion about the social and generic competences required to cope with the constant change itself. Due to the rate of change it is impossible to know what the jobs of tomorrow or the required competences will look like. Popular terms such as ‘work-ready graduates’ and ‘work-based learning’ will have a different meaning and emphasis than they currently have. This paper is addressing some of the recognized knowledge gaps. In particular, the attention is on the connection between construction management functions and digital technologies, and what digital technology competences construction management professionals require.

2. Research method

This paper is part of a larger research project which has the aim of facilitating construction management professionals’ personal development regarding the use of digital technologies (DTs) to respond to the changing competence requirements in construction management created by digitalisation. The research design for the research as a whole is multi-method qualitative research, relying on the constructivist paradigm, seeking an in-depth description of the phenomenon under investigation. A conceptual design framework to support the development of the required competences will be developed based on the research and tested. The research method is a combination of literature reviews, document analyses, interviews and focus groups to inform the different stages of the framework development.

The specific objective of this part of the research is to define and collate the DTs, the construction management functions, and the competences to form a holistic understanding of the research context to assist further analysis. To meet this objective, the following research tasks have been completed:

- The core concepts ‘digital technologies’, ‘construction management’ and ‘competences’ have been defined
- Construction management-specific ‘digital technologies’ have been identified
- A two-dimensional framework of digital technology and construction management functions has been created
- Competences related to construction management-specific digital technologies have been explored.

The research methods used for this part of the research have included a systematic literature review and a document analysis, supported by a traditional state-of-the-art literature review. The systematic literature review aimed to define what DTs are discussed in the context of construction management. The literature review was further intended to identify the scale and pace of the change taking place in construction management-specific digital technologies. This aspect of the literature review was reported in Puolitaival, Kestle and Kähkönen (2018). For the purposes of the current paper, the key contributions from the literature are definitions of ‘digital technologies’ and a list of the most common DTs. Literature has also been used to define the core concepts of ‘construction management’ and ‘competence’ for the context of this research.

The DTs mapping with the construction management functions is intended to work as a base for a multidimensional framework, which will connect the digital technology functions, construction management functions, DTs, DT competences and continuous professional learning. The multidimensional framework addresses the main aim of the larger research project and will be developed at a later stage.

Document analysis was used to identify the current demand for DT competences within the construction management discipline. Job advertisements were analysed to see what employers require

from their ideal candidates. The method has been used successfully to understand specifically the competence/y requirements in several disciplines. For example, in construction discipline Succar et al. (2013) and Barison and Santos (2011) used the method to investigate BIM roles and required competences. The current analysis was qualitative and focused on the cognitive and functional competence requirements, as these were explicitly expressed in the advertisements, unlike the social and meta-competence requirements. The job advertisement analysis was completed in November 2018 and included 295 job advertisements, containing 33 from Finland, 39 from Singapore, 115 from UK and 108 from US.

3. Definitions

To situate the research context properly, the key concepts of the research, ‘construction management’, ‘digital technologies’ and ‘competences’, were defined. There is a wide range of definitions for ‘construction management.’ From these, The Chartered Institute of Building Surveyors’ (CIOB) definition is probably the widest of them. Their inclusive definition is: *“Management of the development, conservation and improvement of the built environment exercised at a variety of levels from the site and project, through the corporate organisations of the industry and its clients, to society as a whole embracing the entire construction value stream from inception to recycling, and focusing upon a commitment to sustainable construction incorporating a wide range of specialist services guided by a system of values demonstrating responsibility to humanity and to the future of our planet informed, supported and challenged by an independent academic discipline.”* (CIOB, 2010) At the other end of the scale, construction management can be defined just as planning, organising, directing and controlling tasks on a construction project (Fryer et al., 2004). As this research focuses on construction project management, Fayol’s management functions were seen applicable: forecast and plan; organise; command; coordinate; and control. Some later work done by authors such as Fryer et al. (2004) and Pilcher (1992) are used to modernise some of Fayol’s wording. More specifically, the word ‘command’ is changed to ‘communicating’ to reflect a less authoritative and more two-way approach to management, to communicate with the individuals and the team(s) instead of commanding them. In addition, monitoring is separated from control, to highlight the different nature of the two: passive for monitoring and active for control. The triangle of time, cost and quality is one of the bases of project management. For the definition, health and safety is included as an important aspect in construction, and also some newer aspects, security and environment, are included. For the purposes of this research the following definition for construction management is used: “Construction management addresses the forecasting and planning, organising, communicating, coordinating, monitoring, and controlling functions required to manage time, cost, quality, health, safety, security and environmental aspects of a construction project”. This research focuses on building construction, differentiated from infrastructure construction and facilities management projects.

In the literature, academic or non-academic, there is no common definition of digital technologies (Puolitaival et al., 2018). In some cases, DTs is a synonym of Information and Communication Technologies (ICT), in some cases it is a subset of ICT or vice versa. The fact that almost all ICT is now in digital format brings DT even closer to ICT. For the purposes of this research, the following definition is used: “Digital technologies include all types of electronic equipment and applications that produce, store or use information in the form of numeric code”. This definition is an adaptation of Hamelink’s definition of ICT from 1997, supplemented by more recent definitions from Ibem and Laryea (2014), and Wong, Ge and He (2018).

The term ‘competence’ instead of ‘competency’ has been used deliberately to separate this work from competency frameworks, which are used for competency assessment purposes. There is a difference between these two terms, but there are also differing views of what the definition and difference is (Moore, Cheng & Dainty, 2002). In this research, ‘competence’ is used as a summary term to include cognitive competence (knowledge and understanding), functional competence (skills), social competence (behaviours and attitudes) and meta-competence (facilitating learning) (Winterton, Delamare-Le Deist & Stringfellow, 2006). This aligns with McConnell’s (2001) definitions of

competence and competency “Competence refers to an individual’s capacity to perform job responsibilities. Competency focuses on an individual’s actual performance in a particular situation” (p. 14). The usage of the term depends on context; ‘competence’ is commonly used as an uncountable noun, but it can also serve as a countable noun if it is about a selection of abilities and knowledge. In the latter case, the plural is ‘competences’.

4. Construction management-specific digital technologies

In this part of the research, two dimensions of the multidimensional framework are explored: digital technology functions and construction management functions. The digital technology functions are derived from work done by Hamelink (1997) and Ibem and Laryea (2014). This research proposes adding ‘manufacturing and installation’ as a construction specific function, as none of the existing functions is able to accommodate additive manufacturing or robotics type of DTs. The DT functions are: data acquisition, storage and processing, displaying and communication, manufacturing and installation, integration and collaboration, and intelligent systems. The construction management functions are derived from the definition developed earlier: forecasting and planning, organising, coordinating, communicating, monitoring, and control. This framework will then accommodate the construction management-specific DTs. As an example, function of a 3D laser scanner as digital technology is data acquisition, and in construction management this data acquisition can be used for planning and monitoring purposes (figure 1).

	Forecasting and planning	Organising	Coordinating	Communicating	Monitoring	Control
Acquisition	3D laser scanner				3D laser scanner	
Storage and processing						
Displaying and communication						
Manufacturing and installation						
Integration and collaboration						
Intelligent systems						

Figure 1. Two-dimensional digital technology and construction management function framework.

In an earlier part of the research, a systematic literature review of quality assured construction management-specific literature was used to identify what digital technologies were discussed in the construction management context. Approximately 100 different examples of DTs were identified. Building Information Modelling (BIM) was preeminently the most discussed example, followed by digital imaging, extended reality, and various monitoring and control technologies, to name a few (Puolitaival et al., 2018). The list can be seen as a snapshot of the current, most common technologies either in use or at prototype stage.

When investigating the DTs further, it was evident that their nature is relatively complex.

- Most DTs identified in the literature review are a combination of other DTs that were also identified. Using the 3D laser scanner example once more, it consists of both hardware and software, which produce the laser beam, control the scanning motion, and collect and store the data. In some cases, a large number of DTs can be entailed, as in the case of Digital twins, which are created by using one selection of hardware and software and managed by using another. What hardware and software is used, varies case by case.
- The DTs sit at different levels. While a 3D laser scanner is a specialised tool in the industry, other DTs are general and enabling in nature such as a computing unit, a mouse, a keyboard, storage systems and networks. It can be argued that the focus should be on more specific DTs, and that enabling technologies should not be included in the mapping at all, as it is not the

role of a construction management professional to understand or manage DTs at this level. Software can sit at different levels as well. While some software is clearly related to specific construction management functions, such as clash detection software for design coordination, general office software tools such as spreadsheets or word processing are ubiquitous in professional environments. While proficiency in both types of software may be important for a construction management professional, generic tools may not necessarily be considered as part of their competence requirements.

- The list of DTs includes hardware and software, and combinations of both. Software cannot be used without appropriate hardware, and in general vice versa. BIM is one example. The technology entails a large number of different types of software and hardware to create the BIM and then to use it. BIM is also connected to various other DTs and it is often difficult to draw the line between them, e.g. where BIM ends and extended reality starts, the same with BIM and Digital twins.
- One DT can mean multiple things depending on the viewpoint of the user. BIM is an example in this case as well. Although BIM has existed for a couple of decades and widely known definitions are available, it still means different things to different people, depending on what their relationship with it is. The relationship is dependent on an individual's profession, role in the project, use of BIM in the project, levels of skills and knowledge about BIM and how to apply it.
- DTs are constantly under change. The core technologies, hardware and software themselves develop quickly, but the number of new applications, which use different hardware and software in different configurations, increases even more rapidly. With this development, the concepts are also evolving and therefore it is often difficult to find common understanding of what they mean. New DTs emerge and move from other industries to construction. Examples of these are extended reality, robotics, sensor technology and IoTs/IoS, Artificial Intelligence and machine learning.
- If grouped, the DTs don't necessarily fit clearly with any of the functions in the framework. For example, wearable technologies are one of the DTs identified in the literature. This label includes clothing, glasses, helmets, and other accessories. However, all these have different functions. They may be used for displaying and communicating information through extended reality, or sensors in them could be monitoring the environment or even controlling user actions.

Due to this complexity, it is clear that a desktop study relying on literature is not sufficient to map the application of DTs to construction management functions. Thus the mapping itself will be co-created with the construction management professionals at a later stage of the research, to allow an in-depth exploration of how they see the DTs as part of their work.

5. Digital technology competences in construction management

The third dimension of the proposed framework is the mapping of digital technology uses and competences to construction management applications. Document analysis, more precisely job advertisement analysis, was used for the purpose. Document analysis as a method doesn't require data collection as such, but instead data selection (Bowen, 2009). Finland, Singapore, United Kingdom (UK) and United States of America (USA) were selected as the countries to be looked at. These countries were chosen as in various studies they have been identified to be in the forefront of BIM (Edirisinghe and London, 2015; Smith, 2014) and the assumption was that therefore they would be in the forefront of other BIM-related DTs and potentially other DTs as well. Also, the countries represent different kinds of markets and are located in different parts of the world, to provide some variety. In Finland, UK and USA, the five biggest construction companies were chosen. These included general contracting and consulting companies, which operate in building construction markets. Singapore required a different approach, as Singaporean companies do not advertise open positions on their websites. Instead, open positions were selected from the Singapore Building and Construction Authority (BCA) website and from LinkedIn. The positions selected in all markets were

construction management roles, including the aspects of managing cost, time, quality, health, safety, security and environment, as included in the definition of construction management which was previously established. Purely administrative, strategic, and other roles which did not require any specific construction industry experience or education, were excluded. Each type of role was included only once from each company. The ‘type of role’ was based on the role requirements e.g. if there were multiple roles called ‘site manager’, all those with different role requirements were selected. Minor differences between role descriptions were overlooked where they did not have any practical impact on the analysis.

The analysis focused on DTs and their associated cognitive and functional competences as explicitly expressed in the job advertisements. Many social and meta-competence requirements such as “effective communicator”, “ability to adapt and manage change”, “self-motivated”, “willing to undertake training and development when appropriate” and “innovative” were also found in the job advertisements. However, analysis of these would have required too many assumptions regarding whether these competence requirements were related to DTs or not, and through that lead to unreliable results.

In most job advertisements, a DT competence was mentioned as a requirement, but this requirement was commonly generic rather than specific to construction management: “basic computer and software skills to include the use of word processing, email, spreadsheets, and electronic presentation” (Construction engineering manager, USA), “proficient in the use of Microsoft packages e.g. Excel, Word and PowerPoint” (various roles, UK) or “good IT skills (various roles, Finland). These generic competences were required either on a basic, intermediate or advanced level, or no level was specified. When a connection was made with the role responsibilities and the DTs, this was most often done by referring to a specific software rather than identifying the type of DT or function for which it was intended. Asta Powerproject, Asta Teamplan, AutoCAD, Autodesk Revit, MS Project, Oracle Primavera, Prolog and Sketch Up were named by multiple companies. In some cases, no details about the software were offered: “proficiency with computer applications as required to perform responsibilities” (Junior field engineer, USA), “proficiency in the use of cost/schedule management systems” (various roles, USA), “confident ability with a range of construction cost management related software” (Cost consultant, UK), “confident ability with a range of construction related software” (Project manager, UK). Some software was mentioned just once or just by one company. Digital hardware was mentioned just by one company with the role of a Quality manager: “experience in the use of digital field tools is essential”. BIM competence requirements were focused on certain companies, and in certain companies in Finland and in the USA it was required across most of the roles. This clearly indicates that certain companies implement BIM in a more holistic manner than others. No conclusions can be drawn regarding whether specific roles had higher DT competence requirements, as this was very much company dependent. For example, some companies did not require site-based staff to have any DT competences, whereas other companies the DT competence list was the most demanding for site-based staff.

The findings show that most companies for most roles do not identify any construction management-specific or advanced DT competences; rather, the expectation is that employees will be proficient in general computer and office software use. Digital hardware, other than general computer use, was even more rarely seen than software, only one company mentioned digital hardware as a competence requirement. This could indicate that:

1. The use of advanced discipline-specific DTs in general in the industry is low. This is supported by the finding that even in the case of very long and detailed competence requirement lists, sometimes as long as 30 bullet points, typical to some US and UK companies, most of the DT competence requirements were generic ones, not specific to construction or construction management. This aligns with the findings of Oesterreich and Teuteberg (2016) and other authors who have studied the challenges of DT adoption in the industry (e.g. Friedrich et al., 2011; Leviäkangas et al., 2017).
2. DT competences are not seen to be as important at the recruitment stage as many other competences. These competences may be seen as something that can be developed in the job.

3. It is difficult for the job descriptions to capture the moving and complex field.

As previously described, the nonspecific nature of the social and meta-competence requirements described in the job advertisements meant that they could not be interpreted in the context of DT competences. However, these remain core competences in most, if not all, construction management roles and so further investigation is necessary to clarify their connection and intersection with both generic and role-specific DTs.

It was expected that the job advertisement analysis would result in a relatively detailed list of DT competence requirements, which could then be used to inform the third dimension in the DT-CM map. Some connections can be drawn, such as competence to use cost management software can be linked to cost management software as the digital technology. Further on, the cost management software can be mapped with forecasting and planning, and monitoring functions on the X-axis and with data storage and processing on the Y-axis of the framework (figure 1). However, in most cases there was not enough information about the DT competence requirements in the job advertisements to make these connections. More research is needed to understand the competence requirements fully, and future work will seek to garner this information directly through interviews with practitioners.

6. Conclusions

The key concepts of this research, ‘digital technologies’, ‘construction management’ and ‘competences’ have been defined, the nature of digital technologies in construction management has been discussed, a two-dimensional framework of digital technologies and construction management functions has been developed, and construction management-specific DTs have been explored. Research methods have included a systematic literature review and a document analysis, supported by state of the art literature reviews.

The ground work, although done for the purposes of this research, can be used in a wide range of contexts and disciplines. The definitions developed are applicable in wider research contexts: DTs definition across disciplines, construction management definition for construction project management, and competence definition again across disciplines, when there is a need to look at capacity to perform instead of assessing actual performance. The expanded DTs functions make the first dimension of the framework applicable in the wider architecture, engineering and construction context, but also in other disciplines which include manufacturing and/or installation.

The discussion on the DTs in construction management context highlights the complexity of the subject. The DTs include hardware and software, most often in various combinations. The DTs sit at different levels, some being more enabling and generic, where others are more specific or applied. DTs can also mean different things to different people, and they are in constant change. The digital technologies-construction management functions framework contributes to the understanding of how DTs are connected through their base function with construction management functions. Also some examples of the mapping are provided, although the mapping itself will be co-created with the construction management professionals at a later stage of the research. Some examples of the third dimension of the framework, DT competences, are also provided, although the findings from the job advertisement analysis did not include enough information to create the frame for the third dimension. Therefore, more research is needed into DTs use in construction management, the related competence requirements, and as part of that, why they are not commonly included in the recruitment process.

Considering the threats and opportunities of the Digital revolution for the construction industry and individual professionals, there is a lot more that needs to be understood to take best advantage of the opportunities and to manage the threats in the best possible way. Many of the job advertisements included social and meta competences which could not be examined in the context of DTs because of the lack of detail provided in the advertisements. These warrant closer examination however, as they

may provide the key for the ongoing development of cognitive and functional competences that allow an individual to cope not only with specific DTs but with the wider change occurring in the industry as a result of digitalisation.

The next stage of the research will continue with further analysis on the required DT competences by more in-depth investigation of how construction management professionals use DTs in their practice within each construction management function and what competences this requires from them. This will be the 3rd dimension of the framework and will also include the investigation of the social and meta competence requirements. Continuous professional learning will complete the framework as the fourth dimension.

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