RESEARCH REPORT

VTT-R-1308-20

Build4Clima final report

Build4Clima - Building for a Healthy Climate

Authors: Pekka Tuominen, Alina Ruonala-Lindgren, Tiina Pöhler, Katariina Torvinen, Sirje Vares, Tomi Erho, Tatu Vienamo, Simon Kay-Jones, Rosana Rubio Hernandez, Johanna Lahti, Sofie Pelsmakers, Fernando Nieto Fernandez

Tampere University

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Summary

Given international and national goals for greenhouse gas emission reductions, there is a clear global need and potential for major reductions in carbon emissions from buildings and construction. Build4Clima is a new ecosystem concentrating on creating new business by turning new and renovated buildings into healthy and circular net carbon capturers over their lifetime. This Business Finland funded Co-creation project lead by VTT and Tampere University addressed the material challenge in the construction industry by bringing together stakeholders by interviews, a webinar, questionnaires and a workshop while forming a common roadmap through a facilitated process. The potential future development avenues identified were: 1) feasibility, cost optimization and impact assessment of carbon neutral solutions, 2) use of space and adaptability/flexibility of buildings, 3) material impact on sustainability and well-being 4) enhancing circularity of building materials and components and 5) flexible construction systems – modularity, prefabrication and hybrid solutions. Development of potential R&D&I topics was done within the framework of these themes and presented in the form of a roadmap. The key insights from the roadmap were 1) Development of low-carbon material solutions should be tied to new building products and concepts, 2) Modular Integrated Construction (MIC) could benefit from standardization of components and collaboration between companies, 3) Global drivers such as urbanization and circular economy should guide development, meaning e.g. modular flexible and movable buildings to cope with changing needs, 4) Development of LCA (life cycle analysis) and LCC (life cycle costing) and their integration with digital design tools such as BIM (Building Information Model) is seen as key enabler 5) Living labs and testbeds offer the opportunity to test new products with manageable costs and acquire references. Moreover, they foster innovation when companies and R&D actors meet and combine their solutions. The participation of stakeholders in this project has revealed great interest and potential for new developments in carbon neutral buildings. The next steps should be moving forward with the development ideas and finding a format for continued collaboration.

Confidentiality	Public

Espoo 10.11.2020

Written by	**Reviewed by**	**Accepted by**
Pekka Tuominen Senior Scientist	Alina Ruonala-Lindgren Co-Creation Manager	Elina Raivio Head of Business Development

VTT's contact address
PL1000, 02044 VTT, Finland

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Preface

Build4Clima ecosystem was conceived as a way to focus the attention of R&D&I activities on the carbon footprint of construction and building materials. As achieving the goal of a zero carbon building is something that no actor can successfully do alone, the need for an ecosystem approach was evident. VTT and Tampere University took the lead in gathering together Finnish companies and other organizations in Build4Clima with funding from Business Finland. Our goal is a carbon neutral and healthy building by focusing on the material use and design of the building spanning its whole life cycle.

Achieving true carbon neutrality in the construction industry is challenging. We also need solutions for buildings to capture carbon during their life cycle. This requires a radically new wide-range network co-operation. To meet these challenges, Build4Clima ecosystem maps the expertise and actors in the field. We bring together players from different industries to create new solutions and business models for the construction industry. Together we have mapped products and concepts that implement circular economy, healthy living environment, carbon-neutral construction processes and carbon capturing in buildings. In this final report we summarize the main findings of the project.

Espoo 10.11.2020

Authors

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1. Introduction

Finland aims to be carbon neutral by 2035 while the European Union has set its goal for 2050. Achieving this goal requires, among other things, that new buildings be largely carbon neutral. Among world's other economies, China has set its sight for carbon neutrality by 2060 while Japan aims for 2050. The building and construction sector is a major source of CO2 globally, and in Finland is associated with about 40% of the energy use and 35% of the country's greenhouse gas emissions, similar to the average EU emissions. Such a major share of emissions means that we need to reduce the carbon footprint of buildings fast, 40 % of total emissions simply cannot be offset by other means.

While the sector has significantly contributed to the current climate crisis, it also means that there is a great mitigation potential (see IPCC, Figure 1). The industry can therefore play a major role in Finland's 2035 carbon neutral ambitions, and becoming carbon negative soon after, as well as in Europe's ambition to be the first climate-neutral continent by 2050 ('The Green Deal'). Besides the necessity to reduce carbon emissions drastically, this must go hand-in-hand with healthy living environment (e.g. good indoor air quality) which is partially influenced by material properties.

Combining these two factors, i.e. the potential of building materials to improve the climate, and to improve people's health and well-being, is what Finnish expertise can build. Our project targets to build for a healthy climate: it can Build4Clima.

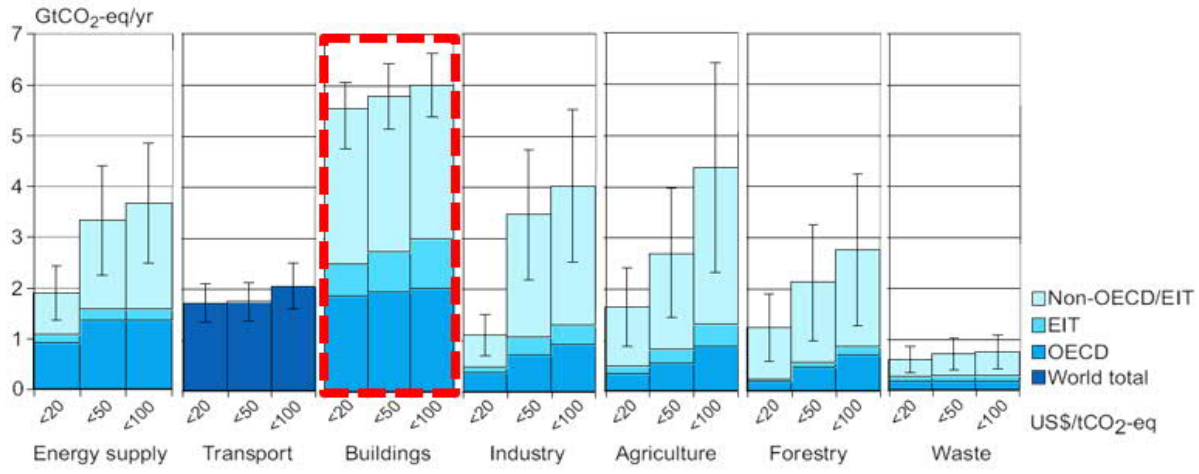

Figure 1. IPCC estimates the greatest mitigation potential in the buildings sector[1].

According to the Ministry of the Environment[2], a building can contribute to climate change mitigation in two ways. By reducing carbon emissions or by having a so-called carbon handprint:

> *'A low-carbon building has a low carbon footprint and a big carbon handprint. A carbon footprint analysis covers a building's entire life cycle. It includes the manufacture and transportation of the products used in a construction project, the worksite, the use and maintenance of the building, its demolition, and recycling'.*
>
> *'The carbon handprint analysis incorporates the net benefits of climate impact that would not arise if there were no construction project. These might be the*

[1] IPCC: Climate Change 2007 – Mitigation of Climate Change

[2] Kuittinen, M. 2019. Method for the whole life carbon assessment of buildings. Publications of the Ministry of the Environment 2019:22 (in Finnish).

building's carbon storages and sinks, the extra renewable energy produced during the building's life cycle, and the benefits gained from the reuse and recycling of the construction products'.

In other words, carbon neutrality of buildings is achieved not only by preventing and minimizing direct CO2 emissions from energy production and improving the energy efficiency of the buildings; but also by additionally strengthening the bio and circular economy in the building sector in a more systemic way. As is shown in Figure 2, the relative CO2 impact of building materials proportionally increases as energy efficiency of buildings improves. The consumption of electricity and heating and cooling energy has long been the biggest emitter over a building's lifespan. This is why energy efficiency has long been in the focus of sustainable building development. This has been successful to such an extent that in most of EU countries emissions from the operation of new buildings have already been reduced in a major way. However, emissions from construction and building materials have remained more or less unchanged. In the next few years, materials will already account for about half of the emissions from a typical new building.

To minimize the carbon footprint, new kinds of materials and their mainstreaming capacity, alongside existing improvements are needed. The building envelope needs to be designed and constructed with minimized material consumption, aided by advanced materials technology expertise and fabrication, together with an understanding of market barriers and stakeholder perceptions of existing and innovative material choices. With renovation and repurposing in mind, more buildings, materials and components will need to be reused to further reduce the carbon impacts, while also understanding the implications of doing so on the fabric and people's health and well-being.

With the recent increase of energy efficiency in buildings, the importance of material quality and environmental friendliness during their life cycle has also increased, owing to concerns about the effect of material off-gassing on human health. At the same time, new bio-based materials and services that support good air quality inside the buildings, also affect building energy use through their hygro-thermal properties, people's behaviour and the design of spaces. These are all factors which affect the choice of building materials.

Clearly, there is great potential in new bio-based materials and services which could offer excellent export potential for Finnish companies across different regions and climates through innovative business models with local manufacturing.

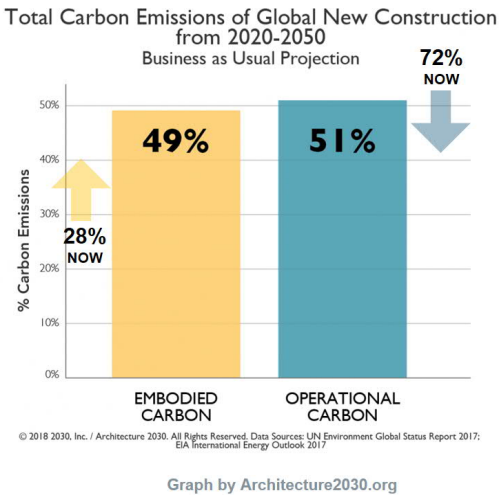

Figure 2. Decreasing operational energy consumption leads to a proportional increase of CO2 from materials.

More broadly, building materials constitute a 1 trillion-dollar industry globally in 2020, while currently only 20-30% of construction and demolition waste is recovered. A global shift to sustainable development by enhancing the recycling and reusing of construction waste material could save $26 trillion by 2030, and create resource wisdom and a circular economy in dealing with the finite resources available, while reducing embodied energy and associated carbon emissions.

Government policies too, across the globe are pushing towards a sustainable and fossil free industry; consumers are increasingly aware of ecological issues and demand eco-friendly products; crude oil prices intensively fluctuate and fossil fuels are depleting.

Estimates of the market size depend on definitions of scope among other things, but various estimates show that the total global market is in the order of hundreds of millions of euros even in the short term. Clearly, while CO2 reductions are no longer optional, the transition towards a carbon neutral society can also lead to new economic and employment opportunities. Recent market studies estimate a global green building materials market of 364 to 377 billion USD by 2022 (Allied Market Research and Grand View Research) and 523 by 2026 (BIS Research).

In the medium to long term, the country specific commitments of signatories to the Paris agreement necessitate that most of the global construction industry will have to be carbon neutral between 2030 and 2050, translating to a market size in the order of 10 trillion USD. Finland, with one of the most ambitious carbon reduction aims in the EU and globally, is hence well placed to lead in this field, and to support other countries' transitions towards carbon neutrality, by exporting its expertise and services in this area.

In support of Finland's 2035 carbon neutral transition challenges ahead, this Build4Clima project and following ecosystem and R&D work aims to strengthen Finnish expertise to produce different carbon neutral and healthy building materials, and creating services and various scalable business opportunities with the expressed goal of Finland becoming a technological leader within a 10 year timespan.

The climate crisis is a global problem, and as such the solutions offer global business potential, however, developing such solutions is a multidisciplinary task requiring co-operation of a variety of partners with complementary know-how and technologies, creating knowledge exchange with a common vision for a roadmap leading to a lower carbon-polluting construction sector.

2. Goal

Build4Clima -project aimed to deliver an overall picture of the company and industry landscape within the bio-material and carbon-neutral construction sector in Finland. Several new business opportunities within the value network were expected to be created as a result of the project.

Additionally to companies, other partner organizations and influencers in the field were needed for a successful execution of the project.

A roadmap was planned to be created in close cooperation between VTT and Tampere University describing the path to a business ecosystem.

The project vision and goals are presented below in Figure 3.

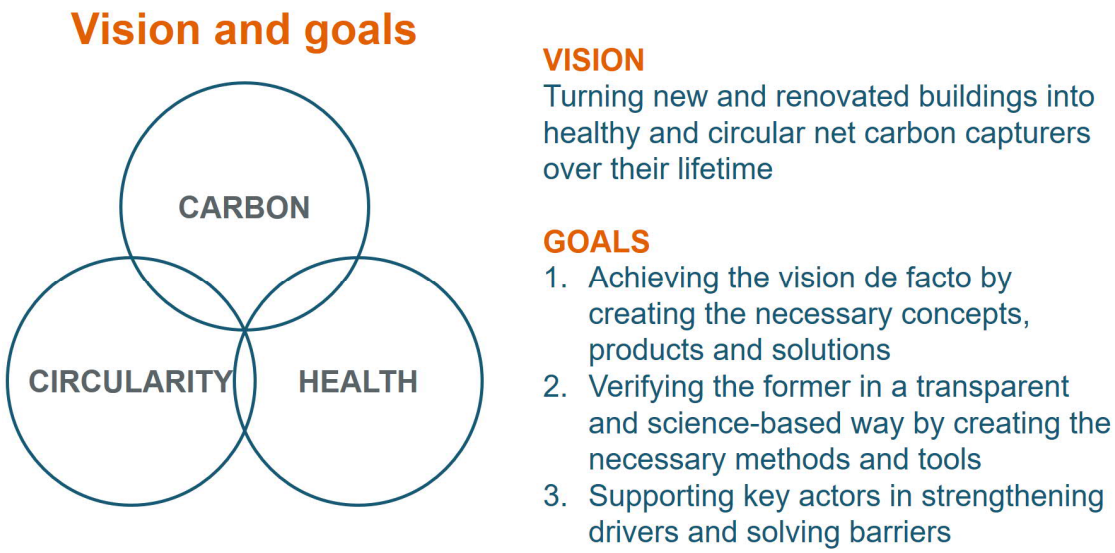

Figure 3. Vision and goals of the Build4Clima co-creation project.

3. Work description

The project addressed the material challenge in the construction industry by bringing together stakeholders who can contribute to better and healthier living environments, find circular business models for construction materials and to create products that are not only carbon neutral but ultimately able to store or capture carbon during their lifespan.

During the project, different stakeholders were interviewed and were planned to be invited to events such as workshops and discussion fora with the goal of understanding their perceptions and need while forming a common roadmap through a facilitated process. The Build4Clima -project is multidisciplinary and requires expertise from various fields of society, given that this is such a challenging task: no one can solve it alone. Therefore this necessitates an ecosystem way of operating and the work will be carried out by two organizations in collaboration: VTT and Tampere University.

The work followed the flow presented in Figure 4 and took place in three work packages as described below:

WP1: Identification of relevant stakeholders, value chains, potential export markets, relevant topics including legislation, regulation and standards, mapping company perceptions, needs and development interest. A webinar was held on 28 May 2020 to promote the project and attract future participation from stakeholders (M1-6).

WP2: Workshop to promote networking amongst the companies and other stakeholders and to discuss their R&D requirements, and barriers to creating new business and growing exports (M3-6).

WP3: Mapping, and selection of technologies and companies and issues for the roadmap needs and interest analysis, relating to potential export markets (M4-6).

The coronavirus outbreak prevented organizing face-to-face workshops with a large number of interested partners. Therefore the activities in WP2 were converted to on-line meetings where the interaction is different compared to a workshop in one physical location.

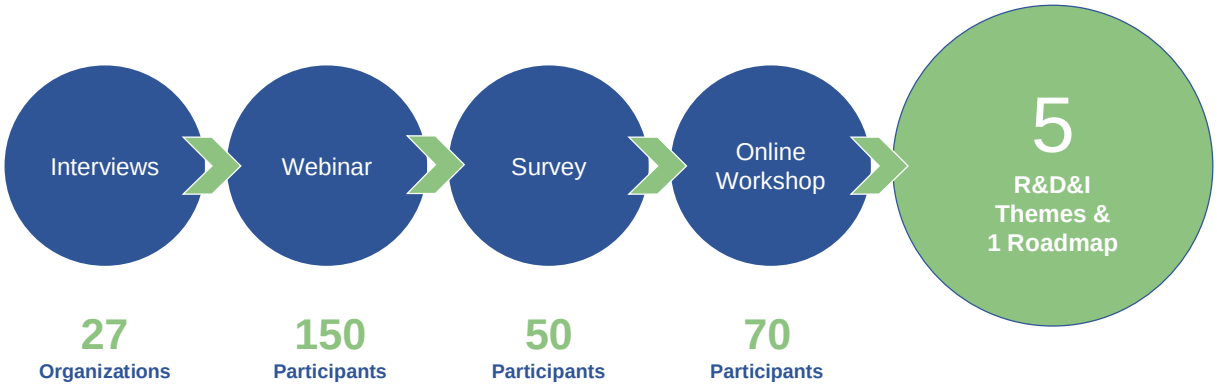

Figure 4 The project flow of Build4Clima.

4. Results

4.1 Interviews

All in all 27 different organizations representing spectrum of different actors and roles, presented in Figure 5, were interviewed in the early phases of the project to get a perspective of each actor's current perception on the status and development needs in the fields of healthy and carbon neutral building. In addition to representatives of Finnish organizations, 6 interviewees represented architect offices abroad.

Figure 5 Types of organizations represented in the interviews.

As a summary of the interviews five possible themes for collaboration opportunities were found. Each of the five themes can constitute a plurality of more detailed development targets. Some of these arisen potential targets are described below in separate paragraphs.

A) Circularity concepts

- Co-developing material lifecycle concepts and business models around use of reclaimed materials, side streams and leftovers from construction industry and other domains

- Co-developing alternative circular raw and construction materials; e.g. recyclable concrete, plastics etc.

- Co-developing design and management strategies for long lasting solutions, e.g. layouts that facilitate flexibility, adaptability, perfectibility and retrofitting.

B) Improved Material Characteristics

- Co-developing energy efficient and ecologically friendly, durable, replaceable materials, building systems and components: e.g. concrete, steel, wood, insulation, glazing, cladding, coating, window films etc.

- Co-developing safer (e.g. fire retardancy, enhanced hygiene, antimicrobial) and healthier (e.g. positive effects on indoor air quality, biofilic design) construction materials, building systems and components.

-Co-developing climate specific building materials and systems, including hybrid solutions.

C) Modularity and Life-Cycle Solutions

- Co-developing collaborative business models and ways of working around modular solutions and life-cycle services.

- Co-developing modular, standardized, and prefabricated (open or volumetric) environmental friendly building solutions and new industry standards for easy installation and maintenance, including Hi and Low Tech.

-Co-developing training for Carbon building and improved construction techniques.

D) Material Impact Assessment

- Co-developing novel solutions and frameworks for measuring and sensoring the current state of construction materials and their impact on the built environment and carbon footprint of the building as well as indoor air quality.

E) Material Banks and Impact Simulations

- Co-developing integrated, standardized material classifications and catalogues

- Co-developing tools helping architects and engineers to choose the right materials and material combinations for the right application

- Co-developing tools for architects and engineers to evaluate the material choices their impact on material and building life-cycle and carbon footprint

Figure 6 describes how the above listed themes and their detailed development targets could be taken into use and create Healthy Carbon Positive Buildings.

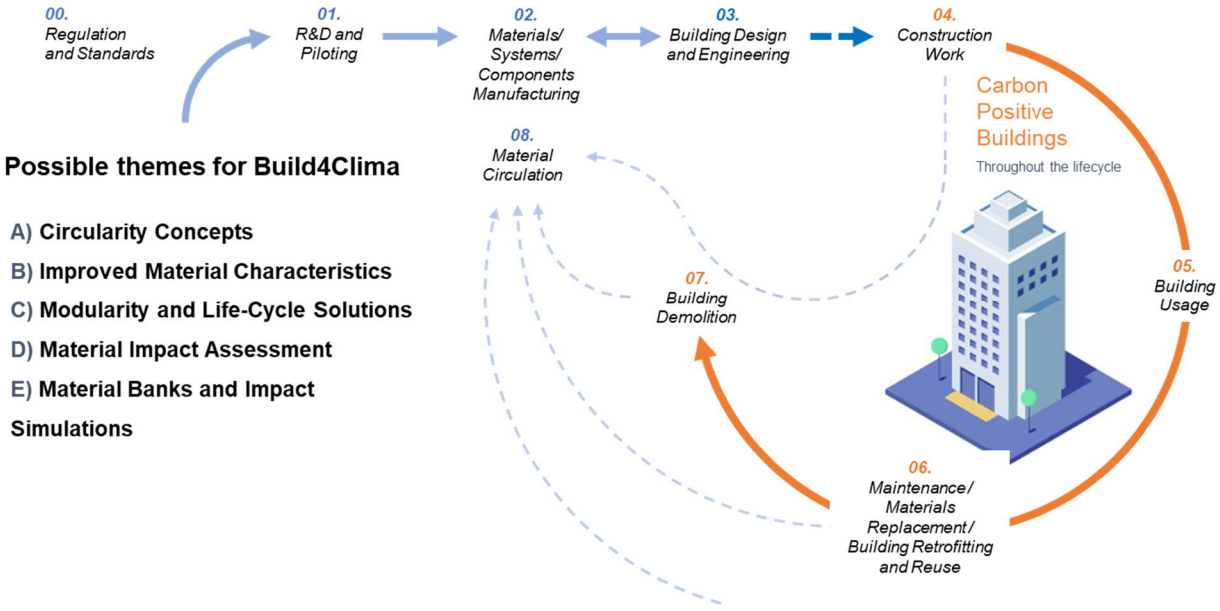

Figure 6. Scheme to turn Build4Clima vision to reality

4.2 Questionnaire and workshop

The main aim of the online stakeholder workshop organized on 24 September 2020 was to co-create a common vision of a roadmap of potential future research, development and innovation topics. To prepare for the workshop and to be able to allocate the participants into smaller subgroups most relevant to their interest, a preparatory online questionnaire exploring the workshop topics was circulated among the participants.

Based on the results of the questionnaire, the workshop participants were divided into subgroups working on the following themes:

1. Feasibility, cost optimization and impact of carbon neutral solutions
2. Use of space and adaptability/flexibility of buildings
3. Material impact on sustainability and well-being
4. Enhancing circularity of building materials and components
5. Flexible construction systems – modularity, prefabrication and hybrid solutions

These themes were developed on templates of potential development ideas, created based on questionnaire results, that were then processed into the roadmap summarized in Figure 7 and presented in full in Appendix 2. Each topic represents a recognized need or opportunity that can either be a topic in itself or part of a larger development project.

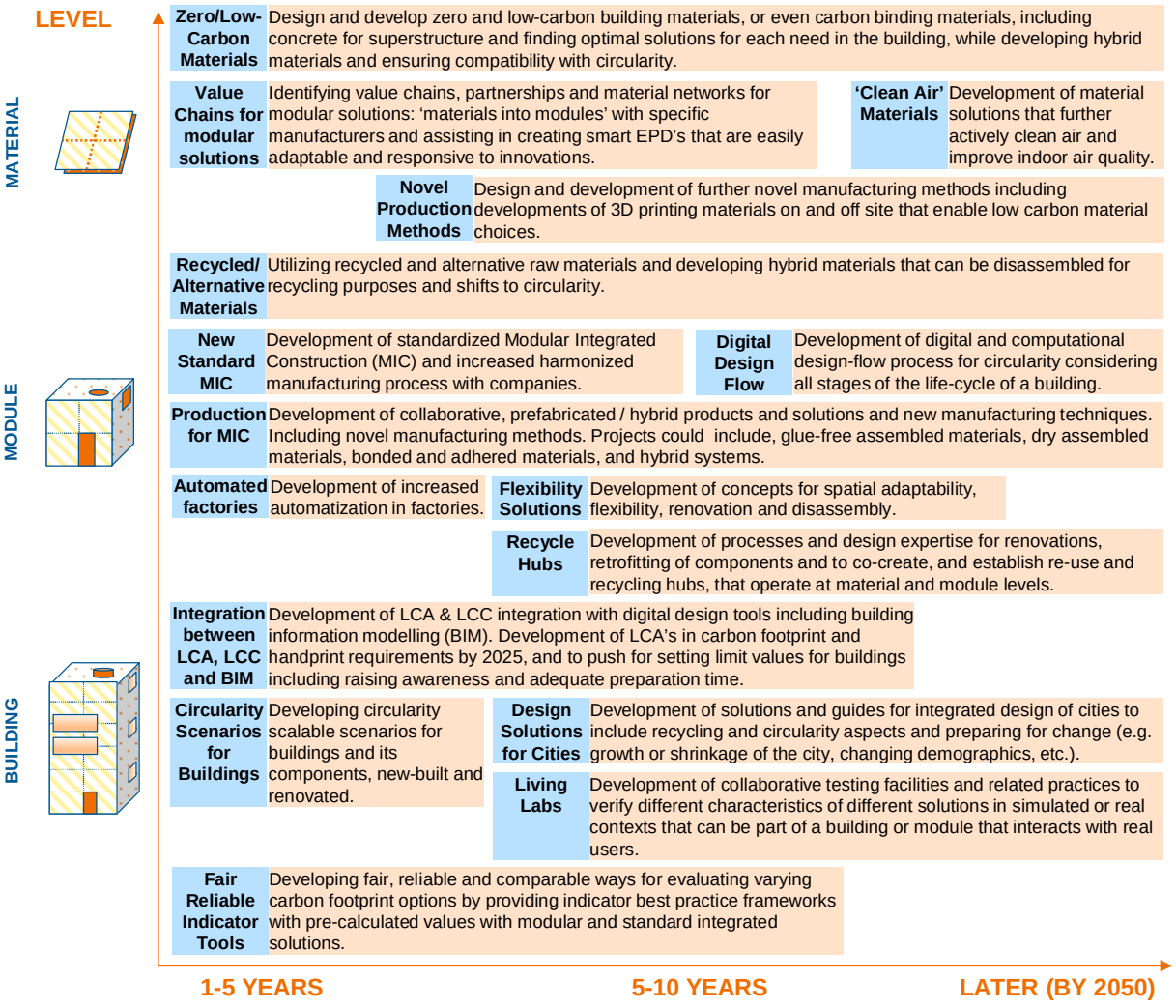

Figure 7 Summary of the roadmap of research, development and innovation topics produced in the stakeholder workshop. Each topic represents a recognized need or opportunity that can either be a topic in itself or part of a larger development project.

4.3 Material and technology review

The relative share of building structure of total embodied carbon gets larger when going from detached houses to high-rise buildings[3]. Structural and supportive building parts represent the largest share of embodied carbon (over 60%) when looking at new mainstream buildings based on steel and concrete structural frames[4]. Production technologies for steel and concrete are about to radically change, demonstrated currently in laboratory scale. However, no fast fixes exist there. New mass timber products as building structure material have been shown as one currently available material option to significantly decrease the embodied carbon in the building structure. Despite of the smaller share of embodied carbon in all other

[3] Strategies for Reducing Embodied Energy and Embodied GHG Emissions. Guideline for Designers and Consultants - Part 2. IEA EBC Annex 57.

[4] A guide to understanding the embodied impacts of construction products. Construction Products Association, 2012. ISBN 978-0-9567726-6-4.

building parts, attention should be paid to material use and low carbon development of insulations, sheathing materials, paints, additives and glues.

To lower the embodied carbon in the building materials Orsini and Marrone[5] have recognized 7 different approaches. Table 1 shows these paths and their relative efficiency in lowering the materials' green-house-gas (GHG) emissions. In addition, adequate training, education and correct information on the materials are needed.

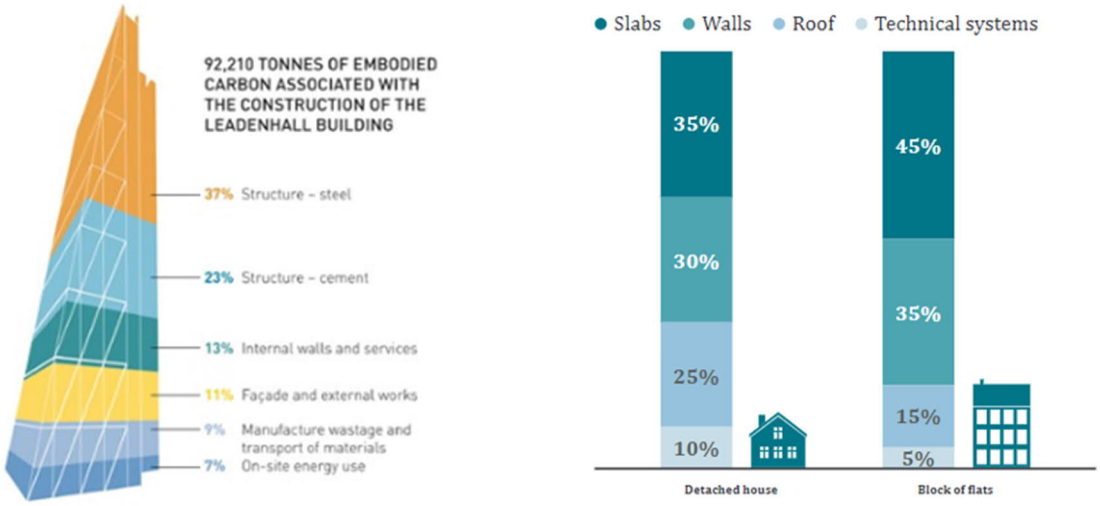

Figure 8. Examples of the division of embodied carbon among different building parts[3,4].

Table 1. Various approaches for low-carbon production of building materials[5].

Approach	Potential in GHG reduction
Use of alternative raw materials	up to -40%
Use of reused, recycled and waste materials	up to -40/50%
Use of natural (minimally processed) materials	up to -90%
Use of local materials	
Innovation of production process, e.g. CCU, CCS	up to -70%
Use of renewable energy sources	up to -60%
Performance increase (e.g. thermal resistance)	

During Build4Clima we mapped state-of-the-art materials and searched for future materials, products and concepts that implement circular economy, healthy living environment, carbon-

[5] Orsini F., Marrone P., Approaches for a low-carbon production of building materials: A review. J. Cleaner Production 241 (2019) 118380.

neutral construction and carbon capturing in buildings. The summary of the findings are shown in Table 2 showing various material groups with their technology-readiness- level (TRL) and attributes from 5 different perspectives: 1) is the material a carbon storage, does it contain biogenic carbon, 2) is the material carbon neutral/negative, can it be produced without fossil-based energy or electricity and does it release CO2 during its production, 3) is the material produced by utilizing CO2 from air or exhausts or is the material able to otherwise capture CO2 along its lifetime, 4) does the material promote circularity by containing either raw materials that are someone's waste or by lacking harmful substances enabling unproblematic recycling, and 5) does the material promote well-being of building's inhabitants by being free from toxics and VOCs or does it possibly actively remove contaminants and buffer moisture variations of in-door air.

Table 2. Examples of current and future materials, products and concepts that implement circular economy, healthy living environment, carbon-neutral construction and carbon capturing in buildings. Insights to the table can be found in Chapter 6.1.

Material	TRL	Carbon storage	Carbon neutral/negative	CO2 utilization/capture	Circularity	Well-being
Fossil free steel	3		•			
CO2 cured alternative binder concrete	3	•	•	•	•	
Vegetal concrete	6	•	•		•	
Biochar containing concrete ad-mixtures, plasters and coatings	3	•		•	•	•
(Fossil) Glue free mass timber materials	6	•	(•)		•	•
Plant and biobased insulation materials	4-9	•	•		•	
Geopolymer/mineral foam insulations	3-9				•	•
Glue-free cellulose based sheathing/building boards	3	•	•		•	•
Green roofs	9	•		•		•
WPC/biocomposites replacing plastic, aluminium and ceramics	4-9	•			•	
New zero VOC, fossil free reactive adhesives	2-3	•	•			•
New, zero VOC, fossil free and non-toxic paints and protective coatings	3-9	•	•	•	•	•

TRL explanations: TRL 1 – basic principles observed, TRL 2 – technology concept formulated, TRL 3 – experimental proof of concept, TRL 4 – technology validated in lab, TRL 5 – technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies), TRL 6 – technology demonstrated in relevant environment TRL 7 – system prototype demonstration in operational environment, TRL 8 – system complete and qualified, TRL 9 – actual system proven in operational environment.

4.4 Legislation standards and assessment systems review

The legislation and assessment of embodied energy within the construction sector is a broad topic with some reports stating over 200 systems[6] with various measures of assessment and verification.

The legislation review was conducted with two expressed objectives aligned to the project's aim: 1) to analyse what barrier to market from a legislation perspective there exists; and 2) to highlight which international standards to focus on strategically to minimize work and increase speed to market.

During Build4Clima we mapped over 215 documents, 98 certifications schemes and 117 regulations, standard and published guidance at national and supra-national levels. We focused on 3 areas or principles to filtering relevant information. 1) that it refers to the construction sector directly and relates to the Build4clima definition of healthy building materials; 2) that it is included in the material categories compiled in the technology review; and 3) that it is either part of the European body of primary or secondary law, or it is verified and proven assessment method, or it is enacted legislation from one of the chosen countries.

A lack of homogenization and variety of rules, guidelines and assessment systems was observed in the different countries that we have assessed. We reviewed five countries specifically for their potential for business development and spread of climatic regions; Finland, Sweden, UK, Spain, EU, and Hong Kong.

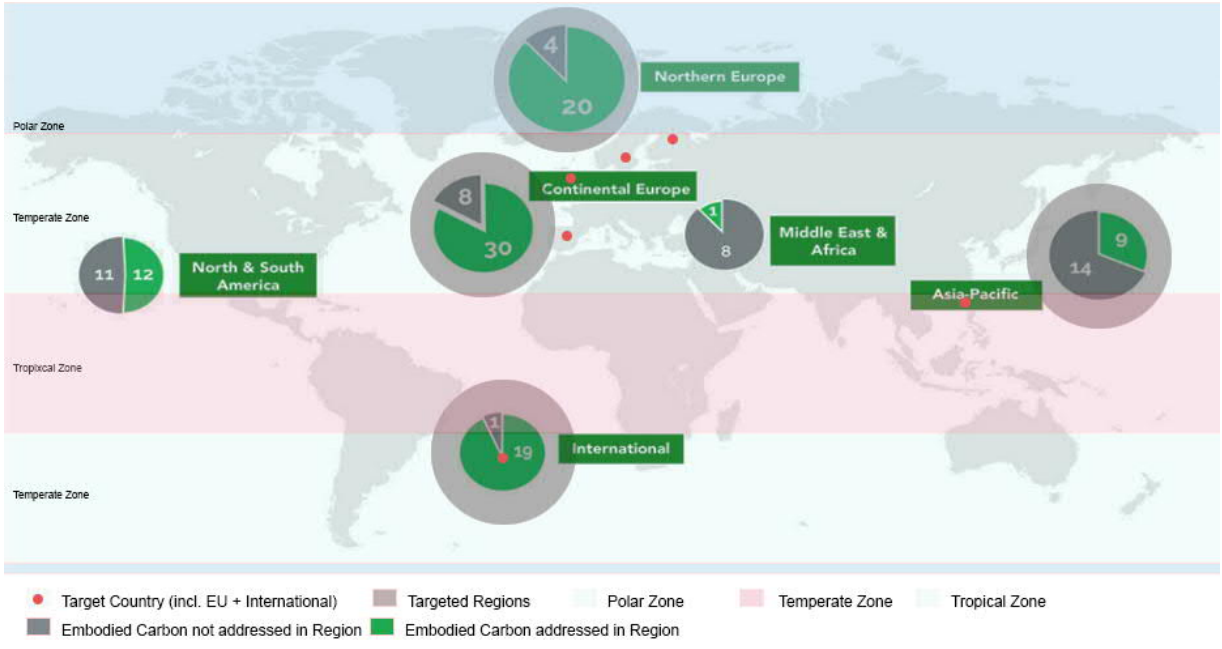

Figure 9 Map of regions and climates chosen for a legislation review. Adapted from the Carbon Review 2018[7].

Following the review there were a number of conclusions the Build4Clima arrived at. Generally, there is a lack of guidance on novel and new materials for zero carbon /EPD across EU and Hong Kong, which leads to the presumption that innovating is difficult or noncompliance is likely. On the demand side legislation is limited. There is a lack of legislations and directives to compel embodied carbon reductions. No limit state is yet active in any region with non-found in building codes. At national level there are no clear targets or legislation that harmonise with the national level objective of zero carbon economies or

[6] The Embodied Carbon Review, 2018 © Bionova Ltd / One Click LCA
[7] The Embodied Carbon Review, 2018 © Bionova Ltd / One Click LCA

national strategies have been enacted. There is a lack of information for LCA/EPD databases and limited awareness of how to use these. There is particularly a lack of knowledge in the existing stock of buildings which might influence the economic, environmental and social impact calculation of whole life emissions of development.

There is a limited legislation across all regions and countries. Legislation is not necessarily a barrier to adoption of materials with low embodied carbon, as far as they comply with the construction product regulations. New materials will specifically need to evidence that they can meet the performance criteria in buildings such as the standards for fire, structure (including wind loads) and toxicity but crucially this is similar to all established materials, therefore the knowledge and expertise in how to use these materials is of more relevance than the perceived legislation barrier.

It is likely that the social and economic drivers play a larger role. Methods of carbon accounting are mixed, and competing methods exist, while integrating into circular economy is difficult due to construction product regulations for new and recycled materials.

Opportunities Generally

There are no barriers highlighted in the legislation and guidance to preclude low embodied carbon materials and Finland is well placed in moving quickly and incentivizing construction sector to integrate low embodied carbon materials into the construction sector through systemic material transitions.

LCA/EPD initiatives will enable a better comparison of varying material service life periods and maintenance with overall whole life accounting in LCA and therefore, may place Finnish companies in a competitive advantage with the high level of skill in designers and construction sector that could commit to roadmaps that integrate low embodied carbon material selection and life cycle assessments; implying a ‘first mover’ benefit.

All countries have a lack of mature legislation at national level with limited scope of recording assessing verifying and comparing embodied energy. For instance, Hong Kong is particularly behind in guidance and legislation, with some regulations, last updated in 1995. As for the UK, the London Plan makes compulsory LCA (including embodied energy calculations) for any projects of a size necessary to be reviewed by the Mayor of London. However, targets are not set and no explicit mention of zero embodied carbon is present. All in all, we can state that at present there are no standards just statements in the countries we reviewed. This offers the opportunities to develop business, products and materials before waiting for legislation to be enacted.

Conclusions and recommendations by country: Hong Kong and Asia

Particularly of note is the Hong Kong and Asian markets that offer considerable market opportunity, with the scale and quantity of developments in what is now being called Modular Integrated Construction (MIC). Across this region there is limited to zero barriers of legislation unique to low carbon products to enter the market, other than the perception by stakeholders. Many of the laboratory test are aligned to the UK standard which at present is harmonized with the EU framework.

Finnish companies with their expertise and experience in biobased construction and high level of skill in designers’ manufacturers, contractors and installers could collaborate to offer compliant MIC module units and or materials that are harmonized within that standardized system.

Furthermore, developing new business models to support and offer consultancy expertise and patentable designs and processes to these markets in designing and utilizing low carbon building is seen as a significant opportunity, rather than the export of materials and construction components.

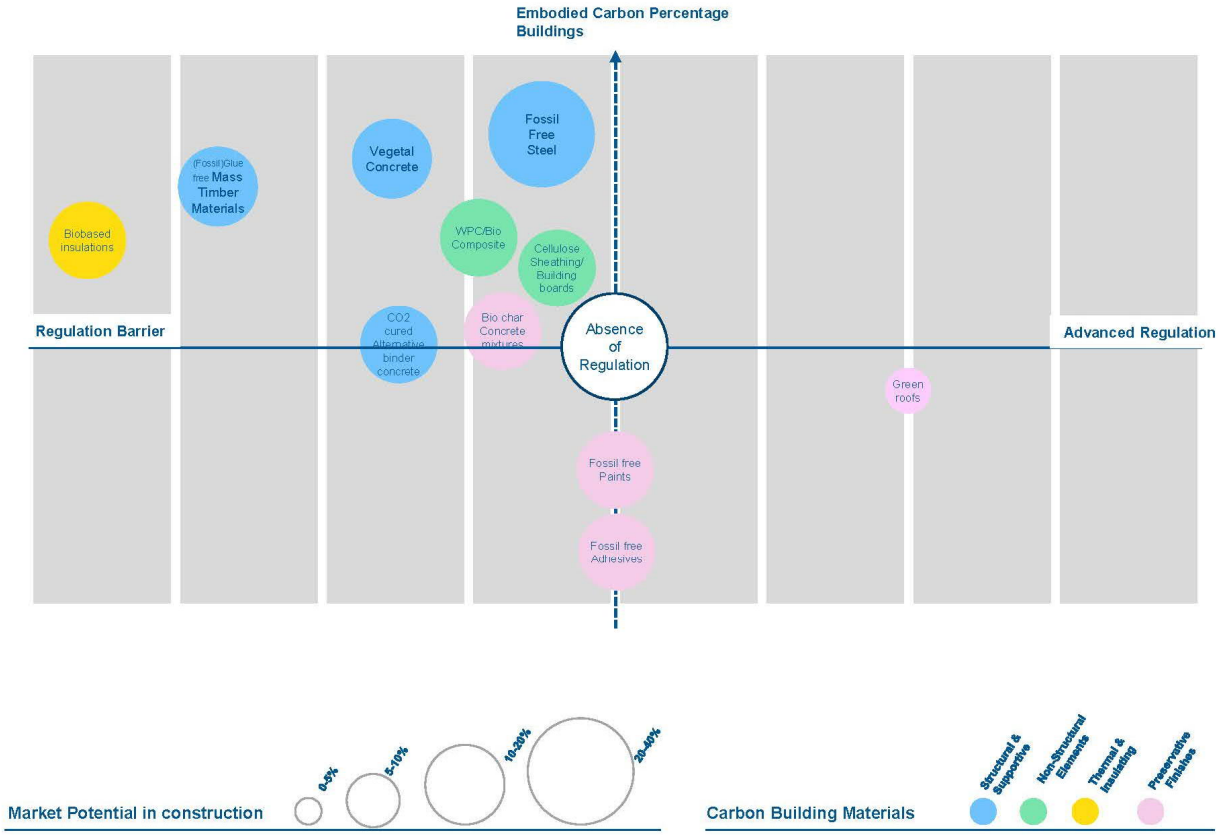

Figure 10 UK and EU overview to legislation barriers and market potential.

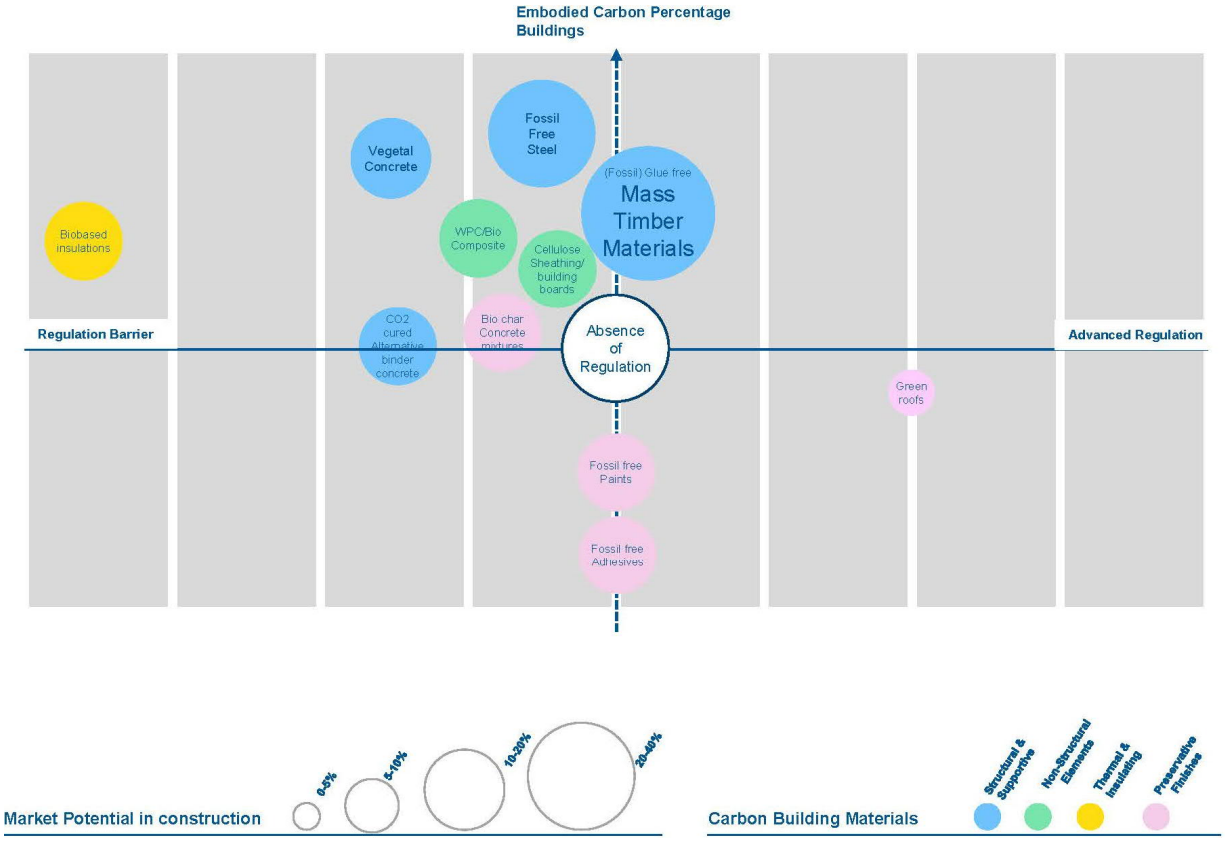

Figure 11 Hong Kong and Asia legislation overview to legislation barriers and market potential.

5. Tools for achieving low carbon buildings

5.1 Low carbon building

Environmentally friendly construction means implementing ‘life cycle thinking’ in setting requirements for construction projects, construction contracting, planning, implementation, and property maintenance.

In low-carbon buildings, requirements are set for the greenhouse gas emissions throughout the building's life cycle, these emissions are caused by the use of land, energy and resources. Once the requirements have been set, the life cycle assessment result must meet at least the level of the set requirement, but this does not prevent the result from being significantly better than the requirement.

In order to manage carbon impacts of construction products and buildings, it is essential to have information on the environmental impact of the various building components and availability of tools to assess the impact of design choices and measures meaning in practice using life cycle assessment (LCA) and life cycle costing (LCC).

5.2 Environmental management of buildings

Building certification systems has been developed for assessing environmental performance of buildings. Great number of building certification systems exists; and most known from them are BREEAM (UK), DGNB (Germany), HQE (France), Miljöbyggnad (Sweden), RTS (Finland), LEED (US), CASBEE (Japan). Even so, that the system is launched in particular country, some of them including also localized versions and thus are widely used in many countries, while other are used only in one country, because has been designed only for the country specific needs, requirements and climate.

5.3 Steering for low carbon construction

Internationally, different instruments and methods for steering construction industry towards low-emissions have been taken into use. Those systems are based on:

- Assessment of total life cycle based CO_2 (Regulation controls the life cycle based carbon efficiency, it also includes the carbon footprint of materials. System used for example in France),
- LCA based total life cycle emissions of construction projects (UK, Belgium),
- Life cycle emission control of construction materials (Austria),
- Cost of environmental damage (Overall environmental damage includes greenhouse gas emissions and other impacts, which are weighted together. Result is a sum of total environmental damage, which is expressed in euros. System used in Netherlands),
- Total energy control (embodied energy) (Switzerland).

In Finland environmental management in construction has long focused on improving the energy efficiency of the building stock and reducing emissions during building operation. With the transition to near-zero energy construction, new energy regulations in 2018 let a little room for the further increase in energy efficiency in building construction and thus decrease carbon-based emissions. The share of building materials in the greenhouse gas emissions of a building is also significant and its relative importance increases, as the energy efficiency of buildings improves and the greenhouse gas emissions during the use phase of buildings decrease.

Most of the emissions from construction materials and products are generated during the manufacturing phase. Currently, these emissions are mainly controlled by voluntary environmental assessment tools for buildings, such as Building Information Environmental Classification, International LEED, the British BREEAM and Finnish RTS. The building's carbon footprint is also a key environmental indicator in the Level(s) environmental reporting system, which is being tested by the European Commission.

To promote and steering 'Low carbon construction' in Finland, Ministry of the Environment put in 2017 into force a three-phase program and the process is still ongoing:

- Phase 1: Testing and methodology development, 2017-2019: development of carbon footprint calculation method and emissions database, tool development, testing in public construction projects and in the private sector.
- Phase 2: Regulatory acts 2019-2025: Preparation of regulatory acts and possible incentives and preparation of monitoring and statistics on emissions data from buildings.
- Phase 3: Take in use in 2025 or earlier: possible staging and monitoring of building stock emission data.

The Nordic ministers decided in 2018 that the harmonization of building regulations should be strengthened. The Nordic working group for LCA, climate and buildings is developed in collaboration with the Nordic building authorities.

Database and assessment tool

In addition to the assessment method, the availability of information on the generic climate impact of products and services is a prerequisite for low-carbon construction. A lot of work has already been done in Finland to find out the climate data of products and processes. Work to compile the data in the database is currently underway under the leadership of SYKE and with the co-operation of VTT, Bionova and other consultants.

The tasks for database project are:

- define generic information,
- identifying building products (selecting, grouping, naming),
- developing background reporting,
- preparing / collecting / proposing GHG values for selected products

In co-operation with the Finnish Green Building Council, an Excel-based tool for the GWP assessment of buildings is being developed. The purpose of this tool is to support and promote the use of life cycle assessment in the design, construction and operation. This open tool is for designers to design low carbon buildings assessment according to the simplified method proposed.

6. Conclusions and recommendations

Given the international and national goals for greenhouse gas emission reductions, there is a clear global need and potential for major reductions in carbon emissions from buildings and construction. Yet this business area is still maturing and in a state of relatively early development. The interviews revealed that very recently, there seems to be a rising interest in carbon neutrality in both the industry and among institutional building owners, as recently as during the past year or two.

Potential future development avenues were identified in the following themes:

- Feasibility, cost optimization and impact assessment of carbon neutral solutions
- Use of space and adaptability/flexibility of buildings
- Material impact on sustainability and well-being
- Enhancing circularity of building materials and components
- Flexible construction systems – modularity, prefabrication and hybrid solutions

Development of potential R&D&I topics was done within the framework of these themes and the results are presented in the form of a roadmap summarized in Figure 7 and presented in full in Appendix 2. Some key insights can be drawn from the results:

- Development of low-carbon material solutions, such as biomaterials, carbon capture and utilization (CCU) and recycled materials, holds great potential but for business success they should be tied to new building products and concepts.
- Modular Integrated Construction (MIC) is promising and further development could benefit from standardization of components and collaboration between different companies.
- Global drivers such as urbanization and movement towards circular economy should guide development. In practice this could mean e.g. modular flexible and adaptable buildings to cope with changing needs.
- Development of LCA and LCC and their integration with digital design tools such as BIM is seen as key enabler across the industry.
- Living labs and testbeds offer the opportunity to test new products with manageable costs and acquire references. Moreover, they foster innovation when different companies and R&D actors meet and combine their solutions.

Some concrete project ideas have resulted from the interactions with the companies, for example:

- Non-hazardous fire protection solutions for low-carbon materials to ensure fitness to circularity and healthy environments.
- Carbon capture and usage in concrete products to create buildings that act as carbon storages.
- Development of standard modular integrated construction (MIC) components to unlock the potential of modularity in the construction industry.
- Developing scenarios of circularity in buildings to recognize and create combinations of products, services and solutions that work as a part of the whole in a circular economy.

The participation of stakeholders in this project has revealed great interest and potential for new developments in carbon neutral buildings. The next steps should be moving forward with the development ideas. Moreover, we foresee usefulness in continuing the exchange of ideas between the stakeholders participating in the Build4Clima ecosystem by finding a format for continued collaboration.

APPENDICES

6.1 Appendix 1: Insights to Table 2.

Developing fossil free steel manufacturing process based for example on replacing coking coal with hydrogen (produced by renewable energy forms) has the highest impact on the carbon footprint of a steel-framed building. However, the material itself does not act as carbon storage or CO2 capturer.

CO2 cured alternative binder concrete has high potential as carbon storage material, it can be produced with a net carbon negative way and during its lifetime it acts as an CO2 capturer. Use of alternative binders may promote material circularity, if for example industrial side streams can be used.

Vegetal/cellulose aggregate concrete is a possible way to increase the carbon sequestered and to lighten the cementitious product. For example lime-hemp concrete is considered to be carbon negative. Side streams from wood industry or hemp oil/seed production can be used promoting material circularity. More knowledge is needed of long-term performance of vegetal concrete in various climate regions. Commercial producers of vegetal concrete outside Finland exist.

Biochar (pyrolyzed biomass) has been studied as a potential concrete supplement that improves concrete strength and water-tightness. Biochar may offer one path to recycle demolition timber and other difficult-to-recycle biomass-based side streams. As a highly porous material, other functionalities like thermal insulation, air purification and moisture balancing are mentioned, thus making it a potential material to promote health and well-being of inhabitants.

Carbon footprint of (conventional) timber in terms of kg GHG/kg of product is typically significantly lower than the corresponding value for concrete, brick and metallic building materials. Other wood products than logs or sawn timber may have significantly higher carbon footprint because of manufacturing processes that may use fossil fuels or because of the content of fossil based glues. Fully glue free timber materials exist that are based on mechanical joints but are not main-stream. Also biobased glue options have been lately taken into use, based on e.g. lignin. Mass timber is a carbon storage material and glue-free products or products with biobased glues ease and promote the material circularity. Development towards formaldehyde free glues promotes the well-being of inhabitants. Wood materials have capability to buffer moisture variations of indoor air.

Insulation materials from renewable plant sources have been used long and are a fairly well known option in building and renovation of detached houses. However, their adoption into the large scale construction business has been slow. Behind that may lie several reasons: their fairly high thermal conductivity values, low fire rating (typically Euroclass E) and protective measures needed at the construction site due to easy wettability and moisture sensitivity in general. In some cases lack of modularity or variation in natural product quality have been seen as an obstacle for larger scale use. However, renewable low density organic fibre insulation materials offer significant opportunity to decrease the carbon footprint of insulation materials, especially if the thermal conductivity of the materials could be further decreased. For example, when mineral wool insulation is changed to cellulose insulation, the amount of calculated GHGs emitted may be decreased by 2...10% (3...10 thousand tonnes) and the amount of calculated stored carbon could be increased by 14% (0...21 thousand tonnes) in a high-rise residential building in Finland.[8]

Porous silica based materials and foamed geopolymers are examples of new mineral/ceramic insulation materials. As an example of a high-performing thermal insulation material, new precipitated silicon oxide materials are non-combustible, do not contain fungicides, algicides, pesticides, fire retardants nor binders. They do not absorb liquid but are permeable to water vapour. It may be that the production of the material itself is not carbon neutral but its high performance (λ<0.020 W/m·K) is of high benefit considering the energy consumption during the use of the building. The high performance also allows thinner insulation layers meaning savings in other material amounts. Lack of added chemical additives is of benefit from emission and health aspects. Foamed geopolymer is a possible new insulation material, with examples of good reported thermal performance and strength.

[8] Ruuska A., Häkkinen T., Potential impact of wood building on GHG emissions. VTT report, 2012.

Geopolymers can be produced from industrial side streams and recycled mineral wools which promotes material circularity.

No glue cellulose based sheathing boards could be an option to replace gypsum wall materials. A prototype of a laminated material structure combining nanocellulose and cellulose plates has been demonstrated. No additional glue was used. The material is fully bio-based and biodegradable. Recycled cellulose materials could be used as well, giving new end-use for e.g. recycled packaging materials.

Green (vegetated) roofs and facades have been shown to conserve energy, reduce noise and air pollution, increase urban biodiversity, sequester carbon and provide a more aesthetically pleasing environment among other things. However, engineered green roof system components and materials (filter fabrics, water proofing membrane, drainage elements etc.) may cause CO_2 emissions during their life cycle. Material development, especially replacement of fossil based plastics, is needed for green-roofing materials for shortening the CO_2 payback time of green roof and façade systems.

Wood-plastic/bio-composites are emerging with a potential to replace high carbon plastic, aluminium and ceramics based building materials. Potential applications include framing, walls and wallboard, window frames, doors, flooring, decking, decorative paneling, cubicle walls and ceiling panels[9], but also bathroom fixtures. In construction, biocomposites could be used for formwork and scaffolding, for instance.

The construction adhesives exist in four main groups: water-based dispersions, hot melt thermoplastics, solvent based glues and reaction adhesives. Of these four, the reaction adhesives have the most negative environmental impact. Petroleum based adhesives may be partially or fully replaced by plant-based compounds. Suitable bio-based compounds for adhesive industry include vegetable oils, proteins, polysaccharides and lignin as well as bio-based monomers such as isosorbide and itaconic acid[10]. For example plywood industry has increased the use of lignin based glues. Solutions to replace hazardous isocyanates in the manufacture of versatile polyurethane polymer are looked for, even utilizing carbon dioxide captured from air as a raw material.

New zero VOC paints and protective coatings based on biomaterials have been investigated. Water-based nanocellulose coatings on wood surfaces have been shown to perform well as a temporary surface treatment. Enhanced water tolerance should be developed. Nanocellulose has been used in a fire retardant paint/coating for wood and textiles by combining it with clay. Lignin compounds can be used to replace synthetic and oil-based paint dispersants. Several novel, non-toxic wood treatments are available for more durable wood facades. Using non-toxic wood treatments is important from recyclability aspect.

[9] http://dev1.kreysler.com/information/specifications/specs-resources/sustainable_biocomposites_for_construction.pdf

[10] Heinrich et al Future opportunities for bio-based adhesives - advantages beyond renewability. Green Chem., 2019, 21, 1866.

6.2 Appendix 2: Expanded roadmap table