DTU Sector Development Project
November 2021

Let us scale circular construction

Preface

The economic significance of the construction sector can be illustrated by the fact that the total investment in construction for the EU-28 countries is twice the investment in industry. Regardless of stock market ups and downs and cyclical fluctuations, the existing building inventory already serves as an anchor for the economic value creation in society. Construction is also of great importance to employment, both in large urban areas and locally. Construction thus plays a key role in the economy.

But the construction sector faces challenges from three important burning platforms that are linked to it: extensive resource consumption, extensive construction waste production, and high carbon emissions. There is a great need for a gradual transformation of the construction sector as we know it, to circular construction. Circular construction is a strategy for the construction sector in which growth is decoupled from the use of natural resources, while the total climate and environmental impacts of society are reduced.

Pilot projects have gained valuable insights during the first outline for a narrative about circular construction. Now we need to go a step further and scale-up circular construction—in relation to new construction, but especially targeting the existing building inventory.

We must start by getting the documentation totally in order, and then follow a number of activities in a roadmap, which include research and innovation, and student and continuing education, broadly within the construction sector. This is all dependent on collaboration across all construction parties and research and education institutions.

This will enable us to realize the great narrative of circular construction.

We hope you enjoy reading the report!

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Our approach

The main purpose of the sector development project is to identify the technological challenges companies face in connection with the transformation to a circular economy in construction. The project also aims to assess which DTU research is needed given the technological challenges. New realizable visions for research and innovation in circular construction have been developed under the project. For research, these visions extend until 2030, and for innovation, until 2024.

The work has provided insight into many challenges and opportunities associated with the transformation to circular construction. Together with companies, public institutions and authorities, and industry associations in Denmark and abroad, we have identified research and framework conditions that can help create solutions that contribute to achieving the 2030 reduction goals for carbon emissions, reduce the amount of waste produced, and ensure lasting access to raw materials.

These were identified through interviews with key people from a number of companies, public institutions and authorities, and industry associations. The results have been 'pressure tested' at a workshop attended by interviewees and at two steering committee meetings attended by representatives of industry associations and the DTU department heads. In parallel with the interviews, workshops, and steering committee meetings, the insights obtained have been discussed at monthly working group meetings for the participating DTU researchers.

The project has been carried out with the participation of researchers from DTU Aqua, DTU Civil Engineering, DTU Compute, DTU Engineering Technology, DTU Chemical Engineering, DTU Management, DTU Mechanical Engineering, DTU Environment, and a sustainability coordinator from DTU CAS. Experts from the Danish Association of Architectural Firms, FRI, and SEGES/Danish Agriculture & Food Council have contributed knowledge and input to the work. DTU Civil Engineering and the Office for Research, Advice, and Innovation at DTU have coordinated. DTU is the report initiator.

The recommendations in the report reflect the dialogue with actors from the sector and across the DTU departments involved.

A sector development project as a tool

Sector development projects are one of the tools DTU uses to collaborate with the business sector and authorities. The aim of the projects is to improve the competitiveness of technology-intensive sectors by creating an overview and action plans for the development and use of new technologies.

The method involves:

- Mapping and analysing the use of technology in the sector, via interviews and workshops
- Identifying bottlenecks and development needs—at companies, authorities, and DTU
- Developing recommendations for research and framework conditions

The sector development projects are created in a forum comprising representatives of companies, authorities and sector associations, in Denmark and abroad, and researchers from DTU.

Introduction

Pilot projects have gained valuable experience with circular construction. But we now need to take the next step and scale circular construction. We must start by having the documentation fully in place, followed by a number of roadmap activities. This will enable us to realize the great narrative of circular construction.

An increasing number of architects, engineers, and clients are experimenting with circular construction. They are trying to incorporate from day one that waste should not end up in landfills or as a filler under motorways, but be used in construction. So far, however, circular construction mostly does not go beyond the pilot project stage.

This is the case even though it is safe to say that there is a burning platform in the construction sector in its current form. Rising urbanization and the growing middle class mean that the world will need to build more than what has been built in the past 4,000 years.

This puts pressure on resources. 50 per cent of the materials we extract are used in construction. In several parts of the construction sector, companies expect increasing problems in obtaining adequate supplies of certain materials.

In addition, construction and production of building materials generate large quantities of waste. A very high proportion of demolished building materials is not recycled, but downgraded: Bio-based materials are converted into energy by combustion, metal is remelted and used in new goods, and heavy materials such as concrete and brick are crushed and used as, for example, a base layer under roads. In the EU, construction waste constitutes 35 per cent of the total quantity of waste.

Construction and production of building materials account for significant greenhouse gas emissions. It is estimated that these emissions constitute 5-12 per cent of the world's total carbon emissions. Calculations show that emissions from the construction sector can be reduced by up to 80 per cent through more efficient use of materials.

In many industrialized countries—including Denmark—the building stock is poorly utilized. 50 per cent of residents find that they live in too large accommodation. In addition, many buildings are left unused or are only used for short periods of time during the day. The utility value of the very large investments in buildings is thus relatively low.

This sector development report is based on the following definition of circular construction:

Circular construction is a strategy for the construction sector in which growth is decoupled from the use of natural resources, while the total climate and environmental impacts of society are reduced.

The framework for the transition to a circular economy consists of three strategies: (a) Creating circular resource flows through recycling, (b) Extending the use and reuse phases of materials through repair, renovation, and remanufacturing, and (c) Reducing the use of natural resources and maximizing the efficiency of production processes.

The crucial importance of the construction sector to the environment, economy, and social aspects of society makes the transition to a circular economy highly complex. Circular construction means a disruption of the construction sector. All players in the value chain must be involved. Rethinking, new ideas, research, and innovation are needed to make a real transition.

The fundamental aspect is that economic growth must be made possible concurrently with lower consumption of primary resources. Therefore, it is necessary that materials and components maintain the highest value for as long as possible. Direct reuse of building parts preserves the intrinsic economic value of the processing of the raw materials during the first production process, and the environmental impact caused by production is stretched out. The decoupling of economic growth from the consumption of raw materials will require circular production and value chains. This requires a new consumption pattern in which utilization of the building stock is optimized.

Table 1. Definition of circular construction and its framework

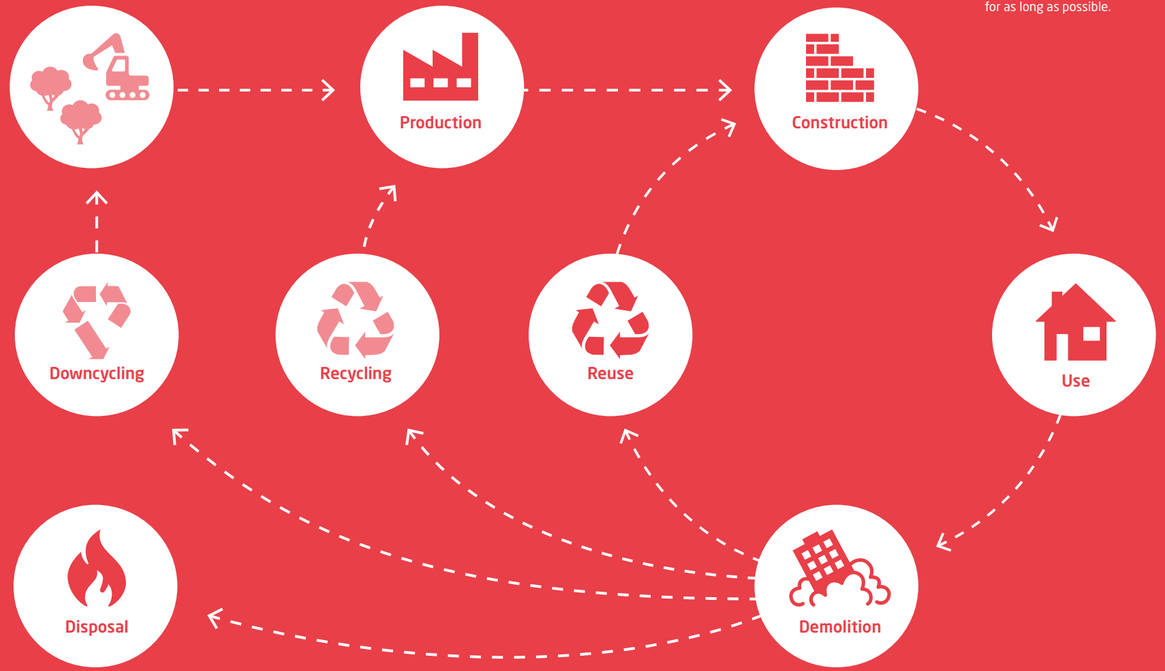


Figure 1.
Graphic illustration of use of materials in the highest value for as long as possible.

The objective of a circular economy is to use the materials with their highest value for as long as possible. In connection with the demolition of buildings, reuse of the materials is thus desired. Today, we utilize construction waste to a high degree. Examples of this are: Wood is burned and energy is harnessed, concrete is crushed and used as a base layer under roads, and metals are remelted into new products. In relation to this, direct reuse and recycling will mean less drain on natural resources for production of new materials (incineration and downcycling), while reuse and recycling in relation to recirculation will mean less production emissions. These correlations are presented graphically in Figure 1.

Scaling of circular construction

The construction sector is challenged by an expected shortage of natural raw materials, high production of waste, and significant climate impacts. Therefore, we must take the step from exciting visions and experiments to broad use of circular construction.

The project has shown that the way forward must necessarily be to scale circular construction. We need to take the insights gained from the best pilot projects and put them into a form so that they can be scaled up.

The quantity of materials in the existing buildings exceeds the total reserves of available building raw materials on the planet. We must therefore stop building only with newly extracted materials. Nevertheless, another important insight from the project shows that there is a tendency to overlook the existing building stock in connection with circular construction. Virtually all pilot projects focus on new builds. Considering the large quantities of valuable materials that our current buildings contain, however, the existing building stock must be the main fulcrum of future actions and initiatives.

Diagnosis of the sector

During the period October 2019 - February 2020, members of the working group for the sector development project interviewed 30 Danish and foreign players in the sector about a number of themes of relevance to circular construction.

One response from the sector is that there is a lack of clear and sustained demand that can drive the circular construction market. This applies to both building materials and building processes. This is mainly due to two factors. Firstly, this is a new market. Secondly, there is a combination of restrictive mechanisms, including planning act, rules on public procurement procedures, executive order on harmful substances, as well as standardization and certification.

Another response from the sector is that there are also considerable challenges on the supplier side.

The development of a market for a new technology, etc. typically depends on both a demand that can drive the development and on a supplier side that is constantly testing new products and processes and gradually drives down the risk, so that more parties on both the demand side and supplier side take part in the development of the market.

On the supplier side in Denmark, this role has currently been undertaken by some small firms of architects. Among larger firms of architects, clients, contractors, building materials manufacturers and consulting engineering firms in the sector, this is being received very positively.

However, medium-sized and large firms of architects are more focused on other important agendas than circular construction. There consequently seems to be a shortage of classic developers of the market on the supplier side which can really push the development forward. This is a structural problem for the development of circular construction.

On this basis, it is an important question whether other players can play the role of developers of the market. It is thus also an important question whether other players can play the role of drivers of the market and, not least, what is needed for them to be able to undertake this role.

Basic model with four levels

A basic model (see Figure 2) has been developed in the project. The model takes into consideration several levels in the transition to circular construction.

The first level of the model consists of the goals that circular construction must meet. These will be goals for business development, good physical frameworks, and decoupling from natural resources.

The next level describes the areas in which action must be taken to meet the goals. The key words are reduction of carbon emissions, limitation of waste, and permanent access to raw materials.

The third level consists of supporting methods, processes, and technologies. This applies to Recirculation of materials, Design for separation, Digitalization, Total Value/LCA/LCC and Structure/management of building processes.

Finally, it is necessary to have a fourth level which describes what changes in framework conditions are necessary to seriously promote circular construction.

The basic model is presented graphically in Figure 2 and is described in detail in Chapters 3-8.

Figure 2.
DTU's basic model for research in circular construction.

Recommendations for 5 strategic initiatives and a roadmap

The overall recommendation is that the players in the construction sector join forces in joint and very large strategic initiatives aimed at scaling of circular construction.

The strategic initiatives must rest on five pillars:

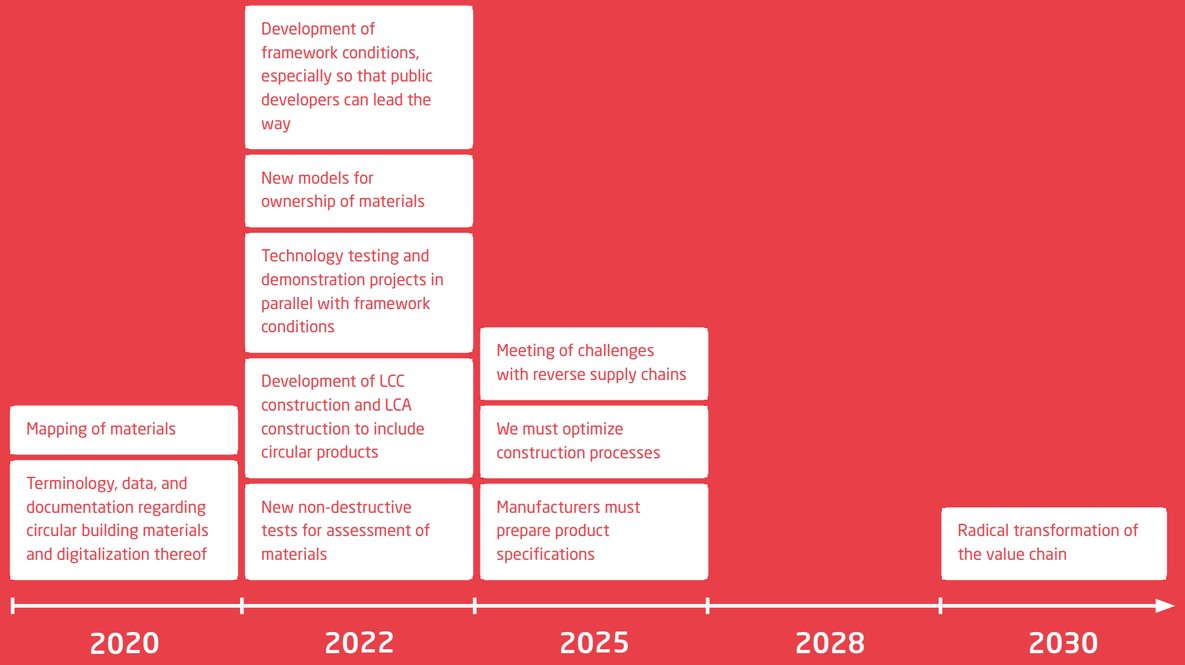
a. They must have renovation of existing buildings as their main fulcrum, but they must also comprise new builds
b. As a central feature, they must have an ambition that all building materials are recovered at the highest level, i.e. reuse of the materials that can technically be reused
c. They must have large and visible effects within all three burning platforms (permanent access to resources, requirements for reduction in the quantity of construction waste and requirements for reduction of carbon emissions)
d. They may be implemented in large-scale test projects which allow for testing of new framework conditions within the applicable legislation and the practical experience basis of the sector ("the shared technological property") and which can form a technical basis for actual scaling, and
e. Development of Denmark as a Living Lab for the World, where the ambition must be to contribute to meeting international challenges by means of both research and innovation.

Inspired by the construction sector in the Netherlands, the players in Denmark can join forces to develop a roadmap for the development over the next 5-10 years which describes – step by step – the combinations of challenges, technologies, and framework conditions that the work will comprise.

DTU wants to enter into a dialogue on a roadmap with the other players in the sector. DTU suggests that this dialogue can be based on the following first rough outline for a roadmap (see Figure 3):

- **2021:** Terminology, data, and documentation regarding circular building materials and digitalization thereof
- **2022:** Development of LCC construction and LCA construction to include circular products, mapping of materials, new models for ownership of materials and development of framework conditions, especially so that public clients can lead the way, as well as new (non-destructive) tests for assessment of materials
- **2023:** Technology testing and demonstration projects in parallel with framework conditions
- **2025:** Manufacturers must prepare product specifications & optimize construction processes
- **2027:** Meeting of challenges with supply chains in circular construction
- **2028:** Radical transformation of the value chain
- **2030:** The great narrative of circular construction is unfolding in full

Figure 3.
Roadmap for the development of circular construction in the period 2020-2030.



The focus is on research and innovation that will be conducted today and that can contribute to solutions by 2030. It is therefore important to note that even the more short-term research and innovation must comprise a 2030 perspective, so that the short-term investments will be aligned with the needs in the period from 2025 and towards 2030.

The parties in the construction sector consist of relatively few very large companies and many small and medium-sized enterprises (SMEs). To enable a transition to circular construction in the sector, it is vital that small and medium-sized enterprises have a central role to play in the implementation of the strategic initiatives/the five pillars and in the activities that follow each other in the roadmap.

Recommendations for research and innovation

01

Research must be conducted into methods for documenting the value of circular building material and of building processes, in both the short term and the long term

It is necessary to be able to document the value of the circular initiatives, both economically and environmentally. A very important element in this documentation is to incorporate the circular mindset in the tools used today—in the design phase, the execution phase, the operation phase, and in certification.

Assessment of total value (LCA and LCC) is important in order to ensure that decisions about the construction of new buildings or renovation of existing buildings are made on an informed basis. These assess a building's environmental impact and costs over its entire life cycle, from 'cradle to grave'. Under the circular strategy, it is necessary to include a chain of life cycles in these principles—that data from before the cradle to after the grave can be included in the calculations.

In the construction sector, consumption of resources is traditionally optimized from an economic perspective. In circular construction, the materials are not only linked to the short-term economics and quality of the project, but require a deeper accounting for the materials' long-term impacts. In other words, existing materials in the building mass must be included in the construction processes. This means methods have to be developed to assess the value of the resources in an existing building.

02

Research must be conducted into the development of technical knowledge that reduces the risk of reusing building materials

In the circular strategy, materials and components must be included in the material flow at the highest possible level (i.e. reuse is better than recycling). The technical documentation requirements for the new application depend on the specific application—for example, whether it is load-bearing structural elements or complementary parts. The technical documentation requirements will generally be higher for reuse than for recycling.

The general requirements for materials and components are laid down in the Building Regulations, and the documentation showing compliance with these requirements is the responsibility of the building owner. This documentation is largely based on experience and guidelines in the technical public domain (standards, guidelines, BYG-ERFA magazines, SBi instructions etc.). Through the acquisition of knowledge and best practice over many years, these seek to reduce construction damage. Reused materials are not incorporated here.

The use of solutions other than those described in the technical public domain is permitted. But if the solution is not described here, the building owner is responsible for showing that the choice is well founded. If problems arise in relation to the chosen solution, there is a significant burden of proof to satisfy in relation to insurance. There is thus a not insignificant risk inherent in choosing solutions that are not described in the technical public domain. To reduce this risk, which is currently borne by building owners who choose re-used components, it is absolutely crucial to develop standards and methods for technical documentation of the quality of re-used components and to incorporate procedures and guidelines for their use in the technical public domain.

03

Research must be conducted into the development of circular processes to ensure scaling from niche to mainstream

Designs, processes, materials, and execution are currently based on the linear model for use of resources. Research and development are necessary in relation to the circular processes.

A dramatic adjustment to construction processes is required: The fragmented organization in construction must be optimized to handle re-use of materials, in well-developed and coordinated value and supply chains. The short-term project focus must be extended to the entire life of the building, with long-term commitments from the participating companies. Finally, the ability to realize construction within the framework of the agreed quality, time, and budget must be improved in relation to qualifying and quantifying the impact of the building.

Access to digital marketplaces, reliable digitally stored information about the products, and automated digitally supported production are necessary for circular principles to become widespread.

04

Research must be conducted into methods and processes to ensure full circularity

We have buildings that have not been built based on the circular mindset—that must become part of the transformation to a circular economy. A major challenge here is that it is difficult to disassemble buildings into usable components and materials. This experience should guide a future strategy that ensures new construction and renovation projects are designed to allow the building to be separated into usable components at the end of its service life. New methods and processes need to be developed for joins between building parts etc. and in composites used.

Design for disassembly is a concept that focuses on how new buildings are designed and planned, and how renovation of existing buildings is carried out. The idea is to prepare for future transformation/ renovation and harvesting of materials for recycling in other buildings (urban mining). The vision is for each building material or component to have a passport containing specifications, which is stored in a 'bank', available to planners and designers (the city as a material bank).

Instead of designing based on ideas and visions and then working out which new materials to use later in the process, they will start with materials and components from the 'bank', and create buildings from these.

Digitalization can help support the spread of circular construction in relation to planning, execution, operation, upgrading, and re-use. Digitalization can be used to record, store, and share data on resources that are already part of existing buildings, and which after use can be included in future renovations, conversions or new buildings. Digitalization can be used to automate calculation of the environmental impacts, economics, and performance of different solution scenarios.

There is also a need for design and decision processes in all phases of construction to be better informed and with a broader perspective, taking into account social and environmental parameters.

05

Research must be conducted into the linking of the value chain for circular construction with other adjacent value chains

Due to the need to balance the energy system when wind and solar energy account for an increasing share of energy sources, the value chains in the energy sector will in future be linked with value chains in, for example, the transport, construction, industry, and water sectors. This means sector coupling, and the establishment of a smart energy system.

In the same way, it is conceivable that the value chains for circular construction will in future be linked to the value chains in interfacing sectors. The idea is that circular construction provides resources that can be used in interfacing sectors, and at the same time receives resources from them that can be used in circular construction.

Research must therefore be done into the coordination and integration of value chains that are not normally coordinated and integrated. In addition to the technological challenges, research will be needed into the framework conditions that apply to each sector and how they can together support the integration of value chains across sectors. The construction sector's relationship to the waste sector is absolutely crucial here for the establishment of efficient circular construction.

06

Research must be conducted into a definition of circular construction and circular construction terminology

Despite the strong strategic focus in both the EU and Denmark on the need to transform the construction sector from a linear to a circular resource economy, the associated terminology and technical concepts have not yet been developed. It is necessary to define and systematize a common understanding of what the concept of 'circular construction' entails in order to avoid miscommunication. We need to define what criteria need to be met in order to be able to say that a building complies with circular principles.

A classification system must be developed for materials and components in circular construction. Not all materials and components have a quality (technical properties and content of chemical substances) that allows direct reuse. Instead, the materials can often be recycled for other purposes after processing, or be utilized in other ways. The classification system must allow a subdivision in relation to the highest possible resource utilization value and the lowest possible carbon emissions.

Given the great importance of the construction sector for resource flows in society, it is necessary to look at circularity beyond the sector alone. Other sectors may increasingly become suppliers of secondary raw materials for construction and vice versa. The conceptualization must encompass this circular economy, linked to activities beyond the sector.

Recommendations on framework conditions, education, testing, and demonstration

07

Research must be conducted into the complex of framework conditions–interpretation of rules on public procurement procedures, standardization, building regulations, hazardous substances, DGNB, and planning act/local plans–and tests must be performed of technologies in parallel with framework conditions in testing and demonstration projects

There is a lack of clear and sustained demand that can drive the market for circular construction (building materials and processes) forward. This is because the market is essentially very new. There is also a combination of limiting mechanisms based on a complex of framework conditions: standardization, hazardous substances, DGNB, interpretation of tender rules, organizational forms, and planning laws/local plans.

There are also significant challenges on the supplier side. The design of a construction project can be 100% negotiated between the architectural firm and the developer before the consultant engineering firm, the contractor, and the building materials manufacturer enter the picture. As the situation currently stands, the scope for designing circular construction can often be very small.

But there are also great opportunities linked to organization on the supplier side. For example, the centralized organization of element production in relation to other countries could be an advantage in relation to scaling circular construction. The challenges on the supplier side are also due to the very broad method freedom on the construction site, which results in low efficiency and extensive waste of building materials.

Research is therefore needed into how the framework conditions can best promote demand for circular construction, and development on the supplier side that increases the scope for designing circular construction. Research is also needed into whether the centralized organization of concrete element production is an advantage, and how it can be exploited if so. Research is therefore needed into how traditional construction waste companies can transform themselves and move their business foundation up the value chain for circular construction, so that construction waste really becomes a valuable resource. And research is needed into how efficiency can be increased and waste of building materials reduced by developing new building methods.

It is important that the research is in the form of testing technologies in parallel with framework conditions in test and demonstration projects, as is being done in the energy sector (e.g. in the smart energy system projects in Nordhavn, on Bornholm, and in Center Denmark in the triangle region).

08

Work must be done to develop Denmark as a Living Lab for the World, where the ambition must be to contribute to meeting international challenges by means of both research and innovation

Denmark, like the Netherlands, is generally seen as being at the forefront of circular construction. Denmark therefore has the chance to take advantage of this opportunity. This can be done by developing Denmark as a Living Lab for the World and thereby helping to meet international challenges using Danish technology and framework conditions.

Research is needed here into what the international challenges are and which technologies and framework conditions can help meet them. Both elements must be an integral part of Denmark as a Living Lab for the World. Innovation projects must also be carried out that can help meet the challenges.

The recommendation that Denmark serve as a Living Lab is deemed to be relevant, particularly for countries in Europe, USA, Australia, and China. In relation to Europe, USA, and Australia, the recommendation applies to both existing buildings and new construction. In relation to China, the recommendation is only relevant to new construction. The reason is that existing buildings in China were built at a time when China was less wealthy as a nation, and are therefore of relatively low quality and cannot be renovated.

09

Interdisciplinary education programmes must be developed and offered to students as well as offers of continuing education.

The project has demonstrated that many of the challenges associated with developing circular construction, such as promoting demand and developing the supplier side, have to be met by technologies that require interdisciplinary research and innovation. This applies, for example, to documentation for the circularity of building materials and how this relates to framework conditions, organization, and collaboration and business models.

It therefore makes sense to develop interdisciplinary study programmes that give students competences in a number of the disciplines that have to be mastered in order to meet the challenges of circular construction. It is also important to develop continuing education opportunities for all parties in the sector—SMEs, large companies, developers, government authorities, carpenters, vocational schools, and employees in hardware stores, so that knowledge, methods and action can be firmly anchored.

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