New needs in construction for circular transitions

Task Report

Authors:

Robert van den Brink

Paula Ala-Kotila

Jyri Hanski

Juha Franssila

Seppo Lähdesmäki

Tiina Vainio-Kaila

Markku Kiviniemi

Kalle Kähkönen

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Abstract

Sustainability is increasingly having an impact on the operating environment of the construction industry. However, there are many different sustainability perspectives available, leading to ambiguity in their application in the industry’s processes. This report looks in more detail to the application of sustainability in design processes. To avoid the same ambiguity in findings as results, after an initial exploration of different sustainability perspectives, this report focuses solely on the application of the circular economy in the construction industry. First, a theoretical framework is set up to aid in circular design. After that, interviews, case studies, and a workshop provide additional findings on how to approach circular design processes in the construction industry. The findings reveal that there is not one single way of approaching circular design processes, but that there is a need for increased collaboration and data sharing when compared to traditional design processes. Based on stakeholders’ information needs throughout the process, different types of technology that could aid stakeholders in the implementation of circular design are also identified.

1 Introduction

The construction industry has a considerable environmental, economic and social impact, as well as a significant raw materials footprint. A such, it has a major potential for contributing to the green transition, but a shift to green construction also faces numerous barriers.

In an economic and social impact, the construction industry is very important to the EU economy. It provides 18 million direct jobs and contributes to about 9% of the EU's GDP. Construction creates new jobs, drives economic growth and provides solutions for social, climate and energy challenges. (European Commission, 2024a). In terms of environmental impact, buildings account for the largest share of total EU final energy consumption (40%) and produce about 35% of all greenhouse emissions. Globally, construction consumes almost half of all raw materials (European Commission, 2020c), and the sector is a major consumer of bulk products like concrete, steel, and aluminum (Herczeg et al., 2014; Liu et al., 2012; Müller et al., 2011; Pauliuk et al., 2013). A look at figure 1-1 shows that concrete aggregates (sand, gravel, and crushed rock) are responsible for the major share of raw material use in the sector. Figure 1-1 also shows that demand for these materials is not decreasing, but rather increasing towards 2060. Deetman et al. (2020) also show an expected rise in demand for construction resources towards 2050, where an increased share of the demand will originate from developing countries. As a continent that is low on resources, from a European perspective this may lead to increased competition for construction materials (European Commission, 2021a; European Parliament, 2020).

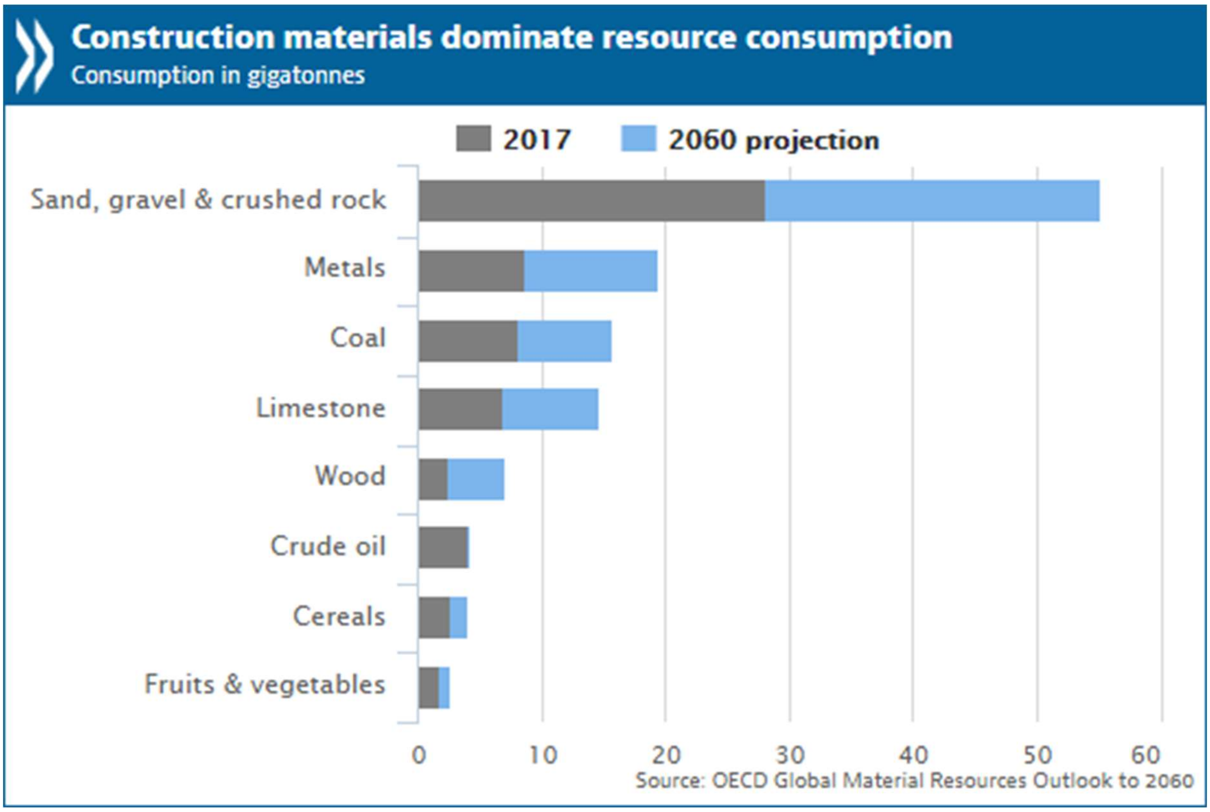

Figure 1-1. Raw materials consumption of construction (OECD, 2019).

At the same time, Construction and Demolition Waste (CDW) accounts for almost 30% of all waste generated within the EU (Source). CDW consists of various fractions including wood, masonry (bricks, concrete, rock), drywall, roofing, plastics (PVC, insulation), and metals. Recovery of these materials is currently largely based on backfilling and low-grade recovery (Cristóbal García et al., 2024). There is therefore a significant potential source of resources that is currently going to waste.

Sustainable efforts in the construction industry have previously mainly focused on the operational emissions originating from buildings, but attention is gradually shifting towards the emissions embodied in buildings' materials, partly as a result of the success of those previous initiatives (Röck et al., 2020). This will shift the focus from the operational phases of buildings towards the design and construction phases of buildings. As circular economy provides a means of both utilizing the untapped potential of the construction industry waste stream, while at the same time enabling drastic embodied emissions reduction (Haakonsen et al., 2024), an increase of relevance and interest in the topic can be expected in the construction industry.

In turn this raises the question how designers can deal with this shift in focus towards the circular economy in their daily operations. This question is at the heart of this report and will be answered throughout the following chapters. The main aim of the report is twofold, (1) to provide background information and create a common understanding for the LiveCol consortium about the requirements and targets of sustainable green construction, with a particular focus on circularity. And (2), to present a collected partners' vision how this will affect design practices and especially the collaboration between stakeholders in a construction project.

In Chapter 2, there is a general description of binding legislation and agreements, as well as voluntary initiatives and actions, targeting sustainable construction from different perspectives. The commonly used formal environmental calculation and evaluation methods, and related standards are also described. These topics are covered at a global, European, and Finnish national level.

Chapter 3 evaluates the impact and applicability of those initiatives introduced in chapter 2 from the perspective of the circular economy. Also a description of legislation and agreements, voluntary initiatives and actions that are specifically aimed at circular economy in the construction industry are presented here.

Chapter 4 will picture the current state of implementation of the circular economy in the construction industry. To support this overview, results of international interviews, case-studies and a workshop are presented here. The main aim of the interviews was to identify current research topics and trends in the circular construction domain in selected European countries, Canada, and Australia, as well as the importance of local factors in the implementation of the circular economy in the construction industry. The findings are subsequently compared and evaluated against LiveCol's overall targets.

Chapter 5 focuses on how the found circular requirements and activities will impact the designers' work, followed by recommendations for the LiveCol consortium (chapter 6), and concluding remarks in chapter 7.

2 Perspectives of sustainability in the construction domain

Sustainability aims to meet present needs without compromising the ecological systems, social justice, and welfare of future generations (Brundtland, 1987). ISO 26000 defines sustainability as a “state of the global system, which includes environmental, social and economic subsystems, in which the needs of the present are met without compromising the ability of future generations to meet their own needs”(ISO 26000, 2010). In principle, sustainability aims for human activities to stay within planetary boundaries. A key concept in sustainability is the Triple Bottom Line, which means that companies should focus on social and environmental impacts of their operations in addition to the economic profits (Elkington, 1998).

This chapter will subsequently address Global, EU, and national binding legislation and agreements, as well as voluntary initiatives and actions that influence the construction industry. Afterwards also sustainability assessment and measurements systems are introduced.

2.1 The global perspective

2.1.1 Existing legislation and agreements

Key agreements include the **Paris Agreement** (2015), where a worldwide binding goal of limiting climate warming below 2 degrees Celsius, while pursuing for 1.5 degrees, was established (United Nations, 2015a). The latest United Nations Climate Change Conference (COP28) reached an agreement that that aims to phase-out fossil fuels and to not exceed the 1.5 degrees Celsius global warming target (United Nations, 2023).

2.1.2 Existing voluntary actions and initiatives

The United Nations’ 17 **Sustainable Development Goals (SDGs)** are perhaps the most known voluntary sustainability initiative (see figure 2-1). SDGs highlight the need for simultaneous improvements in many areas of sustainability from poverty and hunger reduction to strong institutions and peace in order to reach wide sustainable development (United Nations, 2015b). Particularly relevant SDGs for the construction sector are SDG 6 “clean water and sanitation”, SDG 7 “affordable and clean energy”, SDG 8 “Decent work and economic growth”, SDG 9 “industry, innovation and infrastructure”, SDG 11 “sustainable cities and communities”, SDG 12 “responsible consumption and production” and SDG 13 “climate action”. Organizations may adopt the SDG agenda by joining the **UN Global Compact**.

Figure 2-1. Sustainable development goals (source: UN, 2015b).

Related to the aforementioned 1.5 degrees, is the **Science Based Targets initiative (SBTi)**. SBTi is another voluntary action that provides companies with a path to reduce emissions in line with the Paris Agreement goals. The goal is to set the emission reductions in a way that enables limiting climate warming to 1.5 degree Celsius above pre-industrial levels. (Science Based Targets, 2023).

The **GHG Protocol** (Ghgprotocol, 2024) presents a carbon accounting framework for governments, institutions, and companies. Through the protocol, emissions in scope 1 (within own organization), scope 2 (indirect emissions from own organization e.g., purchased energy), and scope 3 (in the organizations value chain, but outside of the own organization) can be calculated and accounted for in a single framework. Adoption is voluntary, but there is a link here to the EU CSRD-Directive.

There are many **sustainability certification schemes** available for buildings. Clients may opt for certification of their building under construction, existing building, or building under renovation. After receiving such a certification, the degree of sustainability of the building has been assessed to comply with a certain predefined level, and it may be compared to other buildings. Generally adopted examples of such certifications schemes are BREEAM and LEED, while e.g., WELL certification assesses the healthiness of a building, and e.g., DGNB is more focused on building performance.

2.2 The EU perspective

2.2.1 Existing legislation and agreements

The EU aims to help the construction sector to become more competitive, resource efficient and sustainable. General sustainability-oriented regulation including the European Green Deal, Circular Economy Action Plan (CEAP), Corporate Social Responsibility directive (CSRD), Corporate

Sustainability Due Diligence Directive (CSDDD) and Critical Raw Materials Act (CRMA) have a major impact on construction. Examples of specific construction related regulation include Energy Performance of Buildings Directive (EPBD), Construction Product Regulation (CPR Acquis), and Waste Framework Directive (Construction and demolition waste).

The EU Green Deal is an umbrella regulation covering all the sustainability related policies and actions in the EU. Its main objective is to make the EU climate neutral by 2050 through targeted action across every industry including construction. By promoting efficient resource use and biodiversity restoration, it aims to reduce pollution and drive a circular economy. Industry resilience is key to the success of the EU Green Deal, which balances sustainability targets with competitiveness at the domestic and global levels. (European Commission, 2019a)

Sustainable finance has key role in delivering the EU Green Deal policy objectives and **EU taxonomy regulation** provides a common language and tool for investors direct investments towards activities with substantial positive climate and environmental impact. The EU Taxonomy puts an emphasis on using recycled and reusable materials, reducing waste, and increasing resource efficiency (European Commission, 2020b). Projects that incorporate these practices and align with the Taxonomy's goals, attract sustainable funding, and encourage agreement with policies like the EU Waste Framework Directive.

The EU taxonomy complements the **Corporate Sustainability Reporting Directive (CSRD)** as companies falling under scope of these have an obligation to disclose alignment of their activities with taxonomy criteria. Other companies may disclose information on a voluntary basis in order to be able to obtain sustainable financing. (European Commission, 2020b). CSRD requires companies to disclose sustainability issues from a "double materiality" perspective, meaning that companies must provide third-party audited reports describing how such issues affect their business and how their business affects people and the environment. CSRD replaces the Non-Financial Reporting Directive, which required companies to provide sustainability reports (European Commission, 2022b).

Corporate Sustainability Due Diligence Directive (CSDDD) requires companies to take responsibility for their environmental and social impacts in their global value chains. Companies affected by the regulation are required to identify and address potential and actual adverse human rights and environmental impacts of company's operations and of their value chain. Also, the directive sets an obligation for large companies to put a transition plan into effect to reach the 2050 climate neutrality objective of the Paris Agreement and its intermediate targets. (European Commission, 2024b)

The **Circular Economy Action Plan (CEAP)** is an umbrella concept which contains many regulations (current and future), including **Ecodesign for Sustainable Products Regulation (ESPR)**, **Digital Product Passport (DPP)**, Directive on Single-use plastics, Right to repair, **Green claims directive** and Proposal for empowering the consumer for the green transition. CEAP aims to make sustainable products the norm in the EU, empower consumers and public buyers, ensure less waste, make circularity work for people, regions, and cities, and lead global efforts on circular economy. ESPR builds on the existing Ecodesign Directive but includes additional product categories and new circularity and sustainability requirements. The ESPR Working plan 2022-2024 covers new energy-related products and updates, and increases the ambition for products that are already regulated as a transitionary measure until the new regulation enters into force. (European Commission, 2020a). However, both ESPR and DPP will be largely covered already by CPR (see 2.2.2) in the construction industry, and a therefore less likely to be adopted separately in the construction industry as well.

The **EU Waste Framework Directive** focuses on reducing waste generation, promoting reuse, and encouraging recycling efforts. The directive establishes a five-level waste hierarchy that mandates prioritizing waste management options in a specific order, with prevention at the top (European Commission, 2008; 2019b; 2023d). Member states are required to foster material recovery, aiming for at least 70% of construction and demolition waste to be recycled or reused.

On a building level, the recently adopted revision of the **Energy Performance of Building Directive (EPBD)** necessitates the calculation of all new buildings' greenhouse gas emissions (global warming potential GWP) from 2030 onwards, along with the creation of digital building renovation passports for existing buildings to map the needed actions to reduce GHG-emissions, and a digital building logbook that contains all relevant information concerning carbon emissions (European Commission, 2023a,c).

2.2.2 Future legislation and agreements

The proposal for the **Green claims directive** provides rules for marketing environmental impacts and basing environmental claims on proven scientific basis. It aims to eliminate greenwashing across EU markets by setting out detailed rules for how companies should market their environmental impacts and performance. It will apply to EU companies and non-EU companies making environmental claims aimed at EU consumers (European Parliament, 2023b).

On a construction product level, the revision of the **Construction Products Regulation (CPR)** will require manufacturers to produce a harmonized Environmental Product Declaration (EPD) to go along with product conformity regulation (i.e. CE-marking). This initiative comes with a digital construction products database and a digital product passport (European Commission, 2022).

2.2.3 Existing voluntary actions and initiatives

The New European Bauhaus (NEB) is an EU policy and initiative launched by the European Commission in 2021, **aimed at fostering sustainable solutions for transforming the built environment and lifestyles in line with the green transition.** This initiative promotes sustainability in the built environment through collaboration among communities, designers, and industry stakeholders. It seeks to develop solutions that are not only sustainable but also inclusive and aesthetically pleasing, while respecting the diverse traditions and cultures across Europe.

The NEB operates by engaging communities at a grassroots level, focusing on neighborhoods and providing tailored tools and guidance. It incorporates feedback from various stakeholders throughout the design and implementation processes, prioritizing social inclusion and economic competitiveness. By promoting innovative architectural practices that integrate circular economy principles, the NEB inspires designers to explore innovative materials and construction techniques that minimize environmental impact. This includes the use of circular economy principles and renewable resources. It significantly contributes to achieving sustainable targets in the built environment, particularly in promoting circularity. By promoting material reuse, recycling, and fostering stakeholder collaboration, the initiative not only meets functional standards but also enhances residents' quality of life and minimizes ecological impact.

In addition, the NEB provides financial support through various funding programs, enabling designers and architects to experiment with cutting-edge ideas and technologies. This support is instrumental in shaping a future where architecture enhances quality of life while reducing ecological impact.

In attempting to provide a common language for assessing and reporting buildings’ sustainability The EU has created **Level(s)**. This is a wider framework for sustainable buildings that addresses buildings’ life-cycle GHG emissions through macro-objectives that consider embodied energy and energy consumption during the use phase (European Commission, 2021b).

2.3 The national perspective

2.3.1 Legislation and agreements

In Finland, the new Building Act comes into force on January 1st 2025, with some provisions being implemented a year later. This legislation introduces several important changes, including the requirement for BIM-based building permits and new requirements for calculating the carbon footprint across the entire lifecycle of a new buildings. The act also sets specific targets for lifecycle properties of buildings to support circular economy goals, encouraging more sustainable construction and material use. By early 2026, detailed legislation will establish carbon emission limit values, and the emissions of the concerning products must be documented in a climate declaration during the handover-phase of new construction projects. The emissions will be presented in the format of a climate declaration that is defined in detailed regulation. The Ministry of the Environment defined a method for emission calculation following international LCA methodologies and standards (see section 2.4), but also provided national emission database[1]. The climate declaration shall be based either on this public,

[1] https://co2data.fi

conservative, emission data or on EPDs of actual products used in the project.

The Building Act was approved in 2023, but amendments have been made in 2024. These changes are set to be approved before the law officially comes into force. The changes reduced the scope of buildings that need to deliver climate declarations, and it is also not required for renovation projects. However, future updates to the regulation are expected, as the Energy Performance of Buildings Directive (EPBD) requires calculation of global warming potential (GWP) for all buildings over 1.000 m2 by 2028 and for all buildings by 2030. This GWP-calculation shall be integrated into the energy certificate, so it is concerning all building types where energy certificate is required.

To support the circular economy, the new Building Act requires documentation of materials used in a construction project, providing a detailed product listing at the handover stage. This listing shall be done at the same level of detail as the design that is presented to authorities in the permitting phase before construction. This product declaration will record main materials and products and their quantities for the later usage of those during the buildings' lifecycle and End Of Life-phase. This information will help to facilitate maintenance, renovations, and potential demolition, promoting reuse and recycling of materials.

The building act also regulates demolition and sets conditions to advance reuse and the circulation of components and materials. Demolition projects require official authorization. The application process must include a detailed declaration of demolition materials and waste, along with a comprehensive description of their intended circulation or disposal.

The national waste legislation that took effect in 2021, and is based on the EU Waste Directive, mandates in its waste setting that at least 70% of construction and demolition waste must be prepared for reuse, recycling, or otherwise utilized as a material (FinLex978/2021). However, the actual preparation of those activities in Finland has so far been around 50-60% (latest numbers from 2021). This requirement excludes earth and stone waste as well as hazardous waste. To comply with the legislation, holders[2] of construction and demolition waste are responsible for organizing waste management on-site. This involves stakeholders prioritizing as much waste as possible for reuse, recycling, or material utilization, such as in earthworks.

2.3.2 Voluntary actions and initiatives

Ministry of the Environment has adopted in Finland the European Green Deal approach to reduce environmental impacts in construction domain. The Ministry has signed Green Deal agreements with several public and private operators. Through these agreements, organizations commit to specific environmental targets, with progress evaluated and outcomes published for each initiative. The latest Green Deal topic in construction focuses on

[2] The party initiating the construction project, the main contractor, or subcontractor responsible for waste management according to a contract or similar arrangement.

promoting a circular economy by reducing natural resource consumption and encouraging low-carbon practices. Previous topics have included emission-free construction sites and reducing plastic use in construction.

One example of voluntary actions is to use environmental objectives as criteria in public procurement or in tenders for the lease or sale of municipal land. A notable example is a housing project in Tampere, where circular economy criteria were used to determine the terms of land leasing.

2.4 Sustainability assessment, measurement and tracking methods

Sustainability assessment is ”a systematic way of analyzing and assessing potential adverse effects on the environmental, social and economic sustainability of a system caused by human activity” (Rödger and Bey, 2019). Benefits of a sustainability assessment include (Valdivia, 2011; European Parliament, 2023):

1) Increased sustainability performance through evaluating sustainability of decision options and consequently designing or selecting more sustainable products.
2) Prioritizing resources and investing them where there are more chances of positive impacts and less chance of negative ones.
3) Clarifying the trade-offs between the three sustainability pillars (see section 2.1), life cycle stages and impacts, products, and generations.
4) New EU legislation and sustainability standards demand transparency in sustainability claims. Transparent communication raises credibility of companies and promotes awareness in value chain actors on sustainability issues.
5) Supporting consumers in determining which products are not only cost-efficient, eco-efficient or socially responsible, but also more sustainable.

Standard-based life cycle sustainability assessment methods include Life cycle assessment (LCA) for environmental impacts, life cycle costing (LCC) for economic impacts, social life cycle assessment (S-LCA) for social impacts and life cycle sustainability assessment (LCSA) for integration of economic, social and environmental impacts. In the built environment their application on a framework level is described in standard EN 15643-1.

LCA is a standardised methodology to assess the **environmental impacts** of products based on standards ISO 14040 (ISO 14040:2006, 2006, p. 14) and ISO 14044 (ISO 14044:2006, 2006). It evaluates environmental impacts of designs over the entire life cycle. LCA has various impact categories such as global warming potential, water consumption and resource depletion. LCA has four process phases: 1) goal and scope definition, 2) inventory analysis, 3) impact assessment, and 4) interpretation. Use cases for LCA include, for instance, product development, public policy making, strategic planning, sustainability reporting and marketing. Incoming EU legislation forces companies to increasingly base their sustainability claims on scientific data and standardized methods. LCA is a key tool for companies to show the environmental performance of their operations. In Europe, LCA is applied in the built environment context through EN 15643-2 on an overall level, through EN 15978 on a building level, and through EN 15804+A2, EN 15941, and EN 15942 on a product level.

LCC is a standard-based methodology to evaluate **economic costs** over the entire life cycle. Generic life cycle costing standard IEC 60300-3-3 (IEC 60300-3-3, 2017) defines LCC as the “process of economic analysis to assess the cost of an item over its life cycles or a portion thereof ”. Life cycle costing process phases according to the standard include: 1) Establishing the organizational context including defining the context for the LCC case and alternatives to compare, 2) Planning the analysis (scope and objective of analysis, constraints, etc.), 3) Defining the analysis approach (LCC model, cost breakdown structure etc.), 4) Performing the analysis (cost data collection, performing LCC and sensitivity analysis), and 5) Finalizing the analysis by identifying follow-up actions and documenting the analysis. In Europe, LCC is applied in the built environment context through EN 15643-4 on an overall level, and through EN 16627 on a building level.

Social Life Cycle Assessment (S-LCA) is a method that evaluates the **social and sociological aspects** of products throughout their life cycle. It assesses the potential positive and negative social impacts associated with a product’s life cycle stages, within five main stakeholder groups: workers, local community, society, consumers, and value chain actors. Impact categories, such as working conditions and cultural heritage, are divided to subcategories such as fair salary and child labour which are assessed with indicators, such as numbers of jobs created, wage gap and number of hours worked by children. S-LCA process is divided to four main phases, same as LCA: 1) goal and scope definition, 2) inventory analysis, 3) impact assessment and 4) interpretation. S-LCA also follows the ISO 14040 (ISO 14040:2006, 2006) framework, although some aspects might differ. The UNEP Guidelines for Social Life Cycle Assessment of Products is a key document providing a framework for conducting S-LCA and presents methodology to develop life cycle inventories for social and socio-economic impacts. In Europe, LCC is applied in the built environment context through EN 15643-3 on an overall level, and through EN 16309+A1 on a building level.

Life Cycle Sustainability Assessment (LCSA) is a comprehensive evaluation method that **integrates environmental, social, and economic impacts** to facilitate sustainable decision-making processes for products throughout their life cycle. Originating from the Environmental Life Cycle Assessment (LCA), LCSA has expanded to include Life Cycle Costing (LCC) and Social LCA (SLCA), embodying the ‘triple bottom line’ (profit, people, and the planet) model of sustainability. Despite its potential, the application of LCSA faces challenges such as the need for practical examples, efficient communication of results, and the development of quantitative indicators for SLCA. Addressing these challenges is crucial for the advancement and wider adoption of LCSA. LCSA is not embedded in the construction context through specific standardization, but since it is made up out of the three previously introduced assessment methods, their standards may be followed to achieve a valid LCSA.

Other than LCA, LCC, S-LCA, and LCSA, **circularity assessments** aim to measure how aligned a product or system is with circularity principles (see chapter 3). It helps to determine circularity performance through the collection, calculation, or compilation of sustainability information. Circularity indicators are used to measure one or more circular aspects by, (1) indicating the circularity of a product, service, company, or a defined system. This utilizes specific methods and indicators such as the material circularity indicator. Or (2) it evaluates the economic and/or environmental impact of circular designs. Here methods like LCA or material flow analysis may be applied. As such, it may either complement sustainability assessments or be a stand-alone assessment. Circularity assessment has several potential benefits: resource efficiency, business opportunities, substitution, minimizing waste, etc. (ISO 59020:2024, 2024). The ISO 59020:2024 standard (ISO 59020:2024, 2024) is a first attempt to standardize circularity assessment indicators and assessment process and is also applicable in the built environment even if specific standardization is not (yet) available. As the draft version of the renewed EN 15978 (prEN 15978 (2023)) does include a circularity annex, this might be resolved soon, however the connection to ISO 59020 is not yet known.

Currently the application of the aforementioned sustainability assessments is concentrated to specific stages of the construction process (e.g., design phase or permit phases). The impacts of the assessments are as such limited to these phases and for certain goals, like obtaining a building permit. As the earlier discussed EPBD-directive includes the adoption of a renovation passport, and the upcoming CPR-regulation includes the adoption of a product passport, we may expect this approach to change in the future to sustainability assessments that are viewed over the entire lifecycle of buildings and products. This is essentially what a **digital product passport** (DPP) aims to do (Koppelaar *et al.*, 2023). As DPP aims to track the history of a product in terms of origin, composition, repair and waste management at the end-of-life (Götz *et al.*, 2022). Each supply chain actor will have access to relevant information on the product and may add data to the DPP during the products life cycle (Koppelaar *et al.*, 2023). The form of these passports is not yet known, and in the absence of an ‘official’ passports, several actors have started to offer early commercial options, for the construction industry for instance by Circularise[3] and Tracid[4].

Ruismäki explored the benefits of DPP for construction (Ruismäki, 2023):
- tracing products allow designers to quickly access information, contractors to manage the duration of construction, or government agencies to improve policy processes
- DPP would especially foster circular practices that extend the lifespan of product and its parts
- tracing product’s history would allow potential customers to make more informed assessments of the condition and quality
- save time during construction and demolition

[3] https://www.circularise.com/
[4] https://tracid.net/traceability

- save time in information retrieval due to the readily available information, eliminating issues of scattered or missing information
- new opportunities in organizing and planning the construction phase, for instance, by optimizing the transportation and positioning of products

Figure 2-2 presents the construction products that are expected to benefit the most from DPP in terms of circularity.

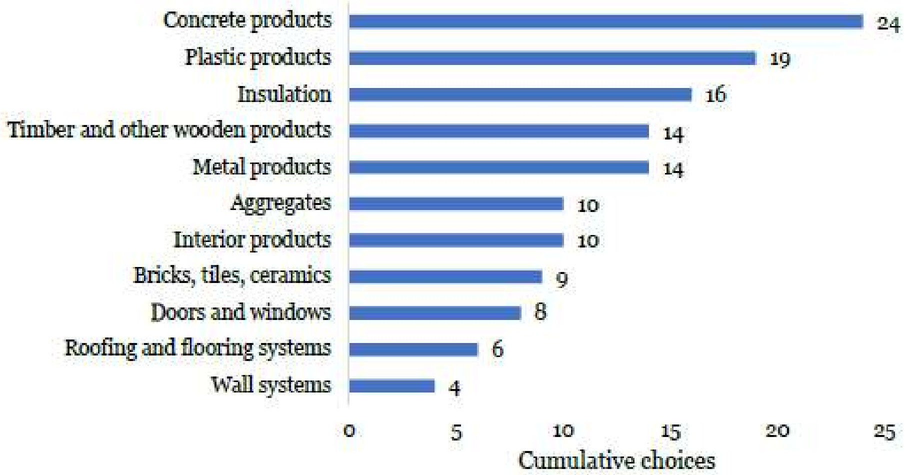

Figure 2-2. Which construction supply chains would benefit from DPP the most in terms of circularity (Ruismäki, 2023).

3 The principles of circular design in the construction industry

From the previous chapter, it is clear that the EU's green & digital transition targets will affect the built environment in the coming years. However, sustainability has proven difficult to implement in practice in the construction industry due to the presence of various barriers. Barriers for sustainable construction include (Karji, Namian and Tafazzoli, 2020; Akcay, 2023):

- High cost of green technologies.
- Inadequate incentive mechanism.
- Resistance of stakeholders to change from the use of traditional technologies.
- Lack of coordination among participants and between different stages of a 'green' construction project.
- Insufficient construction industrialization level.
- Lack of platform to publicize and demonstrate new technologies.
- Lack of market recognition.

Notwithstanding those barriers, the construction industry together with other sectors aims for **climate neutrality** (meaning the reduction of greenhouse gases as much as possible and compensating for the remaining emissions). To reach this goal, the construction sector is tracking, measuring, reporting, and reducing energy, water and material consumption, and embodied energy and carbon. Transforming construction in line with circularity has potential to reduce CO_2e emissions by 84 % and raw materials consumption by 25% by 2050 (Circular Buildings Coalition, 2024). Given the high potential ascribed to the circular economy, this report will from now on focus on this particular view of sustainability among the many that have been introduced in the previous chapter.

3.1 The aim of circular design

Circular economy can be defined as an "economic system that uses a systemic approach to maintain a circular flow of resources, by recovering, retaining or adding to their value, while contributing to sustainable development" (ISO 59020:2024, 2024). Circular economy aims for maximizing material, component and product value and system regeneration in the long-term.

At the foundation of the circular economy is the life cycle perspective, which is familiar from the life cycle analysis methods (LCC, LCA, SLCA). Products are not seen as mere consumables of the present but have a history and a future. The linear life cycle refers to the linear economy model and the so-called 'take, make and dispose' model in which products are extracted, used, and then discarded as waste. Simply put, this type of operating model assumes an endless amount of virgin raw materials to be available for use and pays minimal attention to the waste generated at various stages of the product pipeline. In the circular life cycle or circular economy, the linear life cycle is replaced with circular loops or R-strategies, that enable longer product and material life cycles, less waste, and fewer emissions. In addition to the whole life cycle of a product or system, circular design is linked to systems thinking, which takes into account the broader system in which the product exists and tries to optimize the system-level environmental, economic and social performance of the product.

Circular design means embedding the principles of the circular economy, 1) eliminating waste and pollution, 2) circulating products and materials, and 3) regenerating nature, throughout the design process (Ellen MacArthur Foundation, no date). In general, **eliminating waste and pollution** upstream can be achieved through choosing safe materials designed for repeated circulation, making use of by-products, or engaging in material and product innovation. **Circulating materials and products** can be done by designing them to be kept in use, preferably at their highest value, for as long as possible. Also fostering design for repairability, upgradability and durability and creating life extension business models that allow products and materials to be used more times, by more people, and for longer are relevant design strategies in this category. **Regenerating nature** by designing to improve local biodiversity, air, and water quality considers the creation of conditions for nature to thrive, e.g., by designing for successive cycles in which bio-based materials are used through different applications and are safely returned to the earth after use.

Even though embedding the principles of the circular economy as presented in the previous paragraph might be relatively straightforward for individual products, it is more difficult on a building level. This is because of the typical relationship between materials, products, and buildings, where the building can be seen as a collection of different products and/or materials that together form an entity that can be described as a building. A building is as such a collection of interrelated parts, materials and/or products at different scale levels (adapted from Prins, 1992). Therefore, in the construction industry, there is a need for further specification of the principles before they can be applied in design practices.

3.2 Operationalizing circular design

First, it may be useful to be able to determine the scope of the intended circular design. This does not necessarily have to be the whole building, it might also consist of one or several part(s) of the building. In order to distinguish these parts from one another in the context of a building, we can for instance use the ‘shearing layer’ concept by Brand (1994). His 6S model (see Figure 3-1), distinguishes 6 main building parts for which we may develop a circular design:

- **Site:** This is the geographical setting, the urban location, and the legally defined lot, whose boundaries and context outlast generations of ephemeral buildings.
- **Structure:** The foundation and load-bearing elements are perilous and expensive to change. Structural life ranges from 30-300 years, although few buildings make it past 60 years for other reasons.

- **Skin:** Exterior surfaces now change every twenty years or so, to keep up with fashion or technology. Recent focus on energy costs has led to re-engineered skins that are air-tight and better-insulated.
- **Services:** Includes communications wiring, electrical wiring, plumbing, fire sprinkler systems, heating, ventilating, and air conditioning. They wear out or obsolesce every 7-15 years. Many buildings are demolished early if their outdated systems are too deeply embedded to replace easily.
- **Space plan:** The interior layout - walls, ceilings, floors, windows, and doors. Turbulent commercial space can change every three years, but homes might last 30 years.
- **Stuff:** Chairs, desks, phones, pictures; kitchen appliances, lamps, hairbrushes; all the things that twitch around daily to monthly.

Figure 3-1. 6S model according to Brand (1994) (own image)

After identifying those building parts where we want to apply circular design to, we need to specify the specific strategy or collection of strategies to be used for the circular design. Different frameworks have been presented to describe the possible strategies. For example, R-frameworks (see figure 3-2) have been identified as a measure to contextualize and analyze circular strategies in research projects. Kirchherr et al. (2017) stated that it is difficult to pinpoint a specific article where the R-framework has been introduced, but they identified that multiple different variants can be found: 3R (King et al. 2006, Brennan et al. 2015, Ghisselini et al. 2016), 4R where Kirchherr et al. (2017) added "Recover" from the EU Waste Framework Directive (2008/98/EC), 6Rs (Sihvonen & Ritola 2015) and 9R (van Buren et al. 2016, Potting et al. 2017 & Kivikytö-Reponen et al. 2022). Even though the R-framework offers a well-known option to analyze circular design features, it has a limitation in analyzing only specific aspects of a construction design phase. Therefore, a more specific approach is required to conceptualize and communicate clearly which circular ideas or strategies could be implemented in a construction design process.

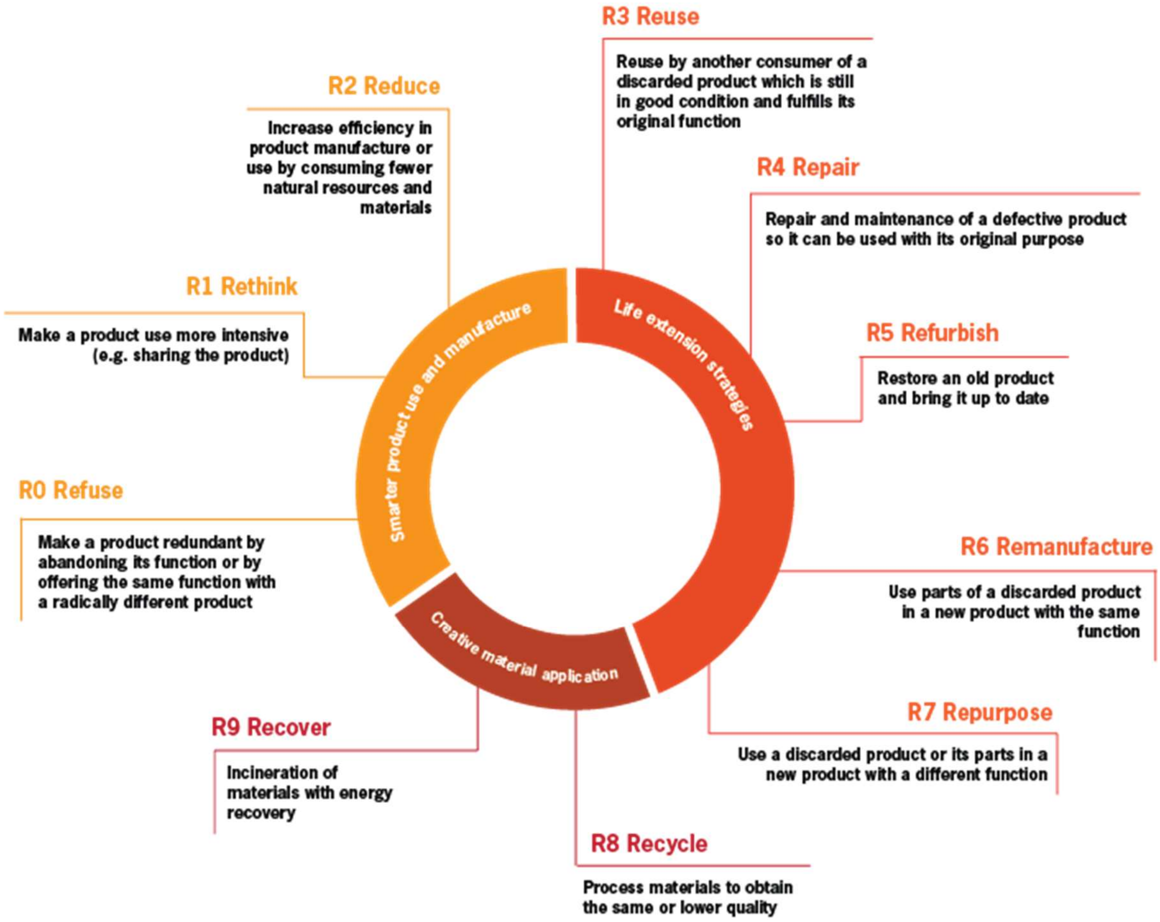

Figure 3-2. R strategies (Kivikytö-Reponen et al., *2022).*

CE has made significant strides in research context but researchers have pointed out that bridging the identified circular design strategies with real-world applications require more work (e.g. Hamida et al. 2023; Nußholz et al. 2023). The CE researchers have introduced multiple different construction industry-specific strategies that aim to reduce the environmental impact of a construction project (Nußholz et al. 2023; Westerholm & Franssila 2023; Eberhardt et al. 2022; Munaro et al. 2022; Kozminska et al. 2019; Ellen MacArthur Foundation 2015). For LiveCol's conceptual framework a total of 20 circularity strategies were identified and selected through a literature survey (see figures 3-3,3-4). Each circular design strategy can be addressed to a CE principle (narrowing, closing, slowing, regenerating) which represents a general goal in a construction project (see figures 3-3,3-4).

Narrowing loops (e.g., reducing raw material use)		Slowing loops (e.g., using products for longer)	
Design for short use	Designing buildings for their specific performance span.	**Design symbiosis**	Using resource outputs from one building as feedstock to other buildings.
Design for component and material optimisation	Reducing the amount and variations of materials and components used.	**Design for durability**	Designing long-lasting buildings with long-lasting components.
Design optimised shapes/ dimensions	Design with precision and specification to optimise the use of material and space.	**Design for assembly/ disassembly**	Reversible connections that allow easy reuse of components.
Design energy-efficiency	Designing buildings that operate energy-efficiently.	**Design for adaptability/ flexibility**	Designing buildings that can adapt to future changes regarding use, function, and available materials.
Design for sharing	Buildings where spaces or equipment are in common use and thus reducing the need for private ownership.	**Design with modularity**	Lean production and standard solutions that allow easier replacement, flexibility, and recycling.
Design for prefabrication	Off-site construction that allows material and time optimisation.	**Design for accessibility**	Providing easy access to connections of components to ease maintenance, repairs, and recycling.
		Design for layer independence	Making components and materials independent from each other's lifespan.

Figure 3-3. Design strategies for narrowing and slowing resource loops in Livecol's conceptual framework.

The selected circular design strategies present a broad overview of different design aspects that can be taken into consideration in a construction project. Selection of specific strategies requires an understanding of their potential to mitigate climate emissions, but they are also strongly context related. This is why some of the strategies have conflicting interests. For example, it is difficult to strive for design for durability and short use at the same time.

Closing resource loops (e.g., recycling material)		Regenerating resource loops (using renewable materials and innovations positively contributing to Nature revival)	
Design for short use	Designing buildings for their specific performance span.	**Design with circular materials**	Choosing or substituting conventional materials with materials that are local, renewable and/or have low negative environmental impacts.
Design symbiosis	Using resource outputs from one building as feedstock to other buildings.		
Design for assembly/ disassembly	Reversible connections that allow easy reuse of components.		
Design with secondary materials	Using recycled or reused materials instead of virgin materials.		
Design with circular materials	Choosing or substituting conventional materials with materials that are local, renewable and/or have low negative environmental impacts.		
Design with standardised solutions	Using standardised solutions (dimensions of components or connections) to ease efficient replacements and recycling.		

Figure 2-4: Design strategies for narrowing and slowing resource loops in Livecol's conceptual framework.

4 The application of circular design in the construction industry

Even though the environmental benefits of adopting circular design in the construction industry are well understood, its application has not become common place in the industry (Çetin et al., 2020; Haakonsen et al., 2024; Mettke, 2010; Nußholz et al., 2019; Van Stijn, 2023). Several barriers have been identified, to some extent comparable as those identified in the introduction of the previous chapter. A frequently reoccurring barrier in literature, and highly relevant from a LiveCol perspective, is the need for increased collaboration and coordination when applying circularity in the construction industry (Hart et al., 2019). Even if this barrier is often cited in literature, apart from findings by Kanters (2020), there is not much information about the ways the design process has to change in order to enable circularity, let alone about the ways in which collaboration, coordination and communication would need to change.

In order to gather more information about the application of circularity in the construction industry, and circular design and the required collaboration, coordination and communication in particular, this chapter presents the results of three different inquiries. First, the findings from seven interviews will be presented. The interviews served two main purposes (1) to validate the background pictured in the first chapters of this report, and (2) to get insight into the application of circular design practices in the countries of the interviewees. The included countries and experts were selected based on their involvement in Trimble Tech Lab-universities, one of LiveCol's partner networks. Secondly, this chapter presents several case-studies to highlight how certain circular strategies may be applied in construction projects. Thirdly, this chapter presents the results of a workshop with LiveCol project participants about the application of certain circular strategies and their impact upon the collaboration process in the construction industry.

4.1 International interviews

The interviews covered a range of topics, including general questions about sustainable construction, the key drivers of circular economy design, the principles of the circular economy, and its future development. Interviews were conducted with representatives from universities in Denmark, Norway, The Netherlands, Sweden, United Kingdom, Australia, and with a technological research institute from Canada. The content of the interviews is presented here anonymously.

These interviews provided valuable additional knowledge and insights into national variations. Sustainable construction was largely viewed similarly across the interviewed countries, with the most significant actions focusing on the reduction of carbon footprints and the improvement of energy efficiency. 'Sharing spaces' was not considered as crucial as other actions (see Figure 4-1), primarily because it was already regarded as standard practice.

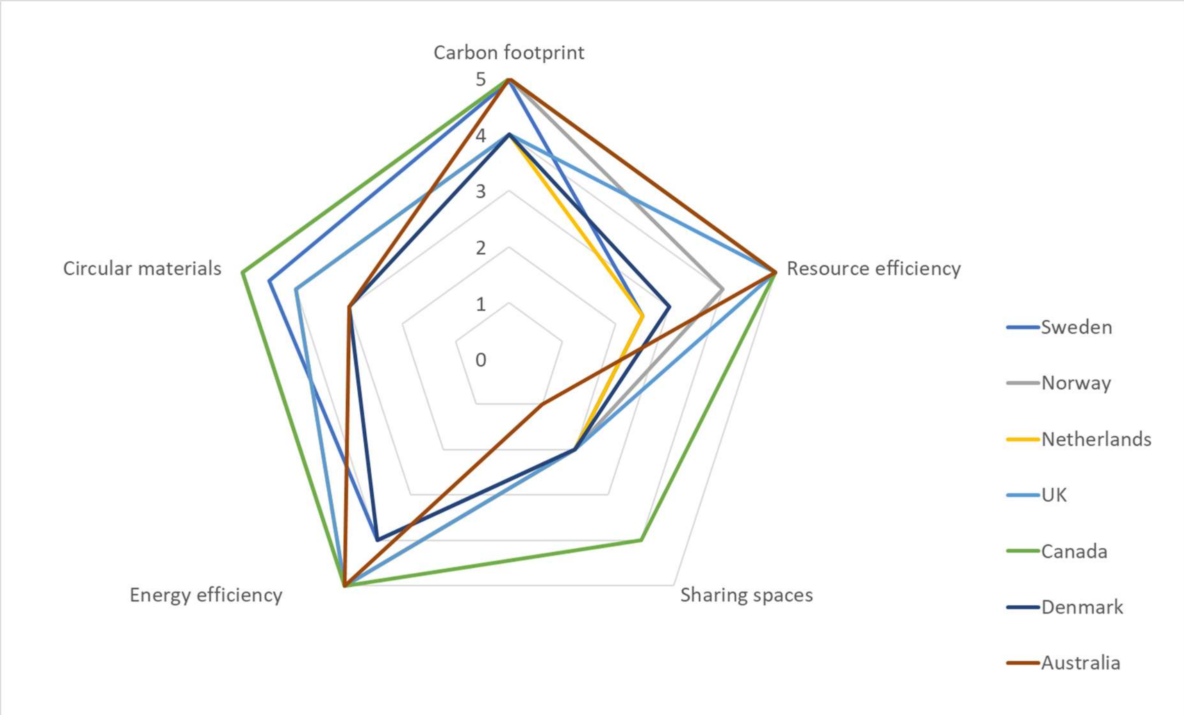

Figure 4-1. How is sustainable construction defined? How important are the following aspects? 1=not important, 2 = very little importance, 3 =neutral, 4= quite important, not in the top, 5=very important

In addition to focusing on circular materials, carbon footprint reduction, resource efficiency, shared spaces, and energy efficiency, the interviewees highlighted several specific sustainability indicators. These include climate adaptation and resilience strategies that prepare communities for climate change impacts, reuse of construction products as a way to minimize waste, and the use of digital technology to support a circular economy by enhancing resource tracking and recycling.

Furthermore, adopting a circular business model promotes continuous resource use, while the concept of social value highlights the broader societal benefits of projects, such as job creation and community engagement. Lastly, ensuring robustness against natural disasters and terrorism is crucial for maintaining safety and durability in construction. The next paragraphs will focus on country-specific findings from the interviews.

Norway

In Norway, the construction sector is increasingly focusing on sustainability and circular economy principles, with an emphasis on wood construction and design for disassembly. Large projects typically have dedicated teams for environmental impact and sustainability, primarily targeting certifications like BREEAM.

Key drivers for circular economy practices include requirements from project owners, technical building regulations (TEK17 in Norway), and evolving laws that support material reuse. Effective circular strategies emphasize design for durability, disassembly, and adaptability, though scaling these practices across the industry is challenging.

A structured process for circular design involves early stakeholder collaboration, evaluating reusable parts, and planning new uses, supported by government regulations and ideally digital product passports linked to BIM models. Although communication between contractors, suppliers, and designers is generally limited, specific projects have shown successful collaboration through workshops and regular meetings. Several start-ups offer services for reuse audits, marketplaces for reclaimed materials, and storage solutions.

Future developments aim to adopt regenerative models that prioritize sustainability, integrate facility management systems, and leveraging digitalization, particularly through digital twins, for better data management.

In conclusion, Norway's construction sector is making significant strides in sustainability and circular economy practices, driven by regulatory support, innovative processes, and collaborative efforts. Continued focus on digital integration and stakeholder collaboration will be crucial for future advancements, ensuring sustainable growth and more widespread implementation of circular practices.

Sweden

In Sweden, the construction sector focuses on sustainability by reducing carbon footprints, preserving biodiversity, and optimizing energy use. Large engineering companies have in-house sustainability experts as part of their design teams. Circular economy practices are driven by client demands, existing waste targets, and some national legal requirements, though specific circular economy laws are lacking. Key strategies include using circular materials, designing for adaptability, and incorporating secondary materials, though implementation is challenging.

Successful circular initiatives include collaborative models, reuse of materials from significant projects, and ambitious goals like Gothenburg’s aim to build apartments with 50% reused materials. While some collaboration between contractors and suppliers exists, it is not widespread.
Emerging service providers, such as Recoma and Wood Tube, offer recycled materials, but a fully functional market for circular solutions is still developing. The Swedish Environmental Institute (IVL) and its subsidiary CCBuild support these efforts, but effective coordination is needed.

Future developments will focus on standardization, better data management through digitalization, and potential third-party marketplaces, despite the challenges they present. Digitalization, including BIM models and possibly digital passports, will be crucial for tracking materials accurately.

While there are promising initiatives and a growing emphasis on sustainable practices, challenges remain in widespread implementation, collaboration, and market development. Continued efforts in standardization, *digitalization, and regulatory support are essential for further advancement.*

The Netherlands

The Netherlands are at the forefront of sustainable and circular economy practices in building design. Several emerging sustainability topics and targets include circularity, public building tenders with circularity targets, life cycle assessments (LCAs) in building permits, carbon footprint reduction, energy efficiency, and the use of circular materials. The country has also set targets for climate adaptation and resilience, as well as the use of nature-based materials.

Design teams often incorporate advisors for sustainability, which is driven by regulations, client demands, and certifications. Key circular strategies include designing for disassembly and modularity to reduce waste and enable reuse, as well as incorporating biobased materials to minimize environmental impact. There is no specific process for implementing circularity into design, but it is often embedded within traditional design processes. Communication and cooperation between contractors, suppliers, and designers are important for successful implementation.

While awareness is high, implementation can be challenging. Some companies are actively working towards circularity, such as those that harvest materials from demolished buildings, use secondary materials in their construction projects, or offer tools like material passports to support circularity. Several circular economy case examples in the Netherlands include the Circular Pavilion, Cepezed's disassembly building, and façade-as-a-service models.

Future developments will likely focus on adapting to changing consumer perspectives and leveraging digitalization through IoT and BIM to facilitate collaboration and material tracking. Overall, the Netherlands is making significant strides in transitioning to a more sustainable and circular built environment.

The United Kingdom

The UK is slowly working towards a more sustainable and circular economy in building design mainly by using BREEAM and LEED certifications. The biggest drivers for applying sustainability and circular economy in UK are net zero carbon targets, client needs and legislation such as the Environmental Act 2021.

In the UK, sustainability and circular economy practices in building design are often led by in-house sustainability managers, particularly in large engineering organizations. For smaller firms or specific projects, the expertise is typically sourced from external sustainability consultants. The most impactful circular strategies in building design include designing with circular materials, design symbiosis and designing with standardized solutions, which is a challenge for the construction sector in the UK. However, in general reducing energy consumption is the most important sustainability action in UK, more than the application of circular strategies.

In practice, the UK is progressing towards a circular economy but faces challenges. Many pilot studies are underway, and companies are already implementing circular economy principles. However, there is a need for more radical thinking and a clearer process for implementing circular design. Communication and cooperation between contractors, suppliers, and designers is crucial, but this depends on the type of contract and the use of digital technologies, such as Building Information Modelling (BIM).

Expected future developments include the establishment of a common framework for circular economy and design, as well as the integration of emerging technologies like AI and IoT. Educating occupants, building users, and professionals will also be crucial in driving the transition to a more circular economy.

Australia

The Australian government has implemented measures to improve sustainability, such as federal and state-based climate change policies (mainly in energy efficiency), industry standards like the NABERS embodied emissions framework, and green star rating systems. These policies require projects to meet certain sustainability targets, such as a percentage reduction in cement usage and energy efficiency ratings. Project costs and related incentives are big drivers as well.

There are examples of repurposing high-rise buildings, modular schools and prisons, and the use of recycled plastics in concrete, timber waste in structural walls, and wood-plastic composite decking.
In practice, downcycling materials and modular construction are common, but construction sites still generate a significant amount of waste, indicating a gap between promotion and practice. There is a lack of monitoring after the construction phase, which is a current gap in the implementation of circular design. Communication and cooperation between contractors, suppliers, and designers regarding circular economy depend on the client's drive and the decisions made by the sustainability engineer. BIM is widely used in the industry, and different building companies keep BIMs in their archives, but there is no centralized storage system.

Expected further developments in the domain include research on extracting heavy metals, disassembly and assembly, and the use of AI to support circular economy practices. The government is also working on regulations for reducing primary material usage, which will further drive the adoption of circular economy principles in the construction sector.

Australia is actively evolving in terms of circularity, with a focus on modular construction, the use of recycled materials, and design for disassembly. Energy efficiency plays a significant role as well. However, there is still a need for more education and awareness among construction workers, as well as a significant amount of generated waste in the industry.

Denmark

Denmark places emphasis on building conservation and regenerative design, focusing on renovating existing structures to preserve their environmental value and reduce the impact of new construction. Regenerative buildings, which use biobased materials, aim to maximize environmental benefits, and reduce energy consumption by reusing structural components and enhancing biodiversity. New CO2 regulations, set to take effect in 2025, will also demand the calculation of transportation (A4) construction site (A5) emissions. Regulations will extend to all buildings, including single-family homes and summer houses, encouraging the use of Environmental Product Declarations (EPDs) for materials. Although challenges persist with reused materials lacking standardized values.

Selective demolition will become mandatory from July 2024, requiring authorized demolition companies to follow comprehensive plans that ensure materials are reused appropriately. Architects play a crucial role in incorporating circular principles into designs, particularly for sustainability certifications.

Denmark employs both immediate strategies, such as using recycled materials, and future-oriented ones, such as ensuring that buildings can be easily modified. Key strategies include design symbiosis, adaptability, and standardized solutions. Although pilot projects and initiatives are in place, large-scale adoption remains limited. Enhanced collaboration and new digital solutions, like digital twins and augmented reality for pre-demolition audits, are expected to advance circular practices.

Denmark is making improvements in integrating circular economy principles into construction through regulatory support and innovative design strategies. Challenges remain, especially in scaling up, but the focus on sustainability and resource efficiency is driving progress toward more environmentally friendly building practices.

Canada

Canada is increasingly prioritizing sustainable practices in the construction sector, aiming for all buildings to achieve net-zero carbon emissions by 2040. This goal includes significant reductions in the carbon footprint of key materials like concrete and steel, as well as improving building envelopes' energy efficiency, and reducing greenhouse gas emissions. The introduction of new low-carbon requirements in the National Building Code, which is currently under development, will play a crucial role in this effort. These requirements will also support workforce training for low-carbon construction and renovation practices.

The integration of circular economy principles is supported by specialized consultancies (such as Footprint, S3R and Adaptis), which guide sustainable and circular design practices. These expanding firms help businesses optimize waste management and utilize AI tools for efficient construction planning and material use.

Regulatory frameworks, government policies and market demand are major drivers for adopting circular and sustainable economy practices in Canada. The overall approach to circularity combines strategies that balance immediate impacts, such as the use of recycled materials, with long-term goals like design for disassembly and energy efficiency. The government’s broader strategy to meet 2030 emissions targets also aligns with these efforts. However, challenges remain, particularly in harmonizing environmental codes between the U.S. and Canada, as well as among Canada's provinces.

In practice, reusing and reclaiming materials, design for disassembly, and design for energy efficiency (e.g., integration of renewable energy systems) is common. It is recognized that effective collaboration among stakeholders, including architects, designers, and suppliers, is crucial for successfully implementing these strategies. Circular Economy Leadership Canada (CELC) provides leadership and expertise and fosters collaboration within the circular economy community by connecting local and global networks. Digital solutions, such as Building Information Modeling (BIM), material passports and digital twins, are increasingly being used to track materials throughout their lifecycle, reduce waste, and improve design efficiency.

Canada's construction sector is gradually embracing the circular economy, but widespread adoption is still developing. To accelerate progress, stronger regulatory support, enhanced collaboration, and ongoing innovation in design practices will be essential. The establishment of circular construction innovation hubs and increased cooperation among government, industry, and academia are expected to drive this transition. Although scaling these efforts is challenging, Canada's focus on sustainability and resource efficiency is set to greatly improve the construction industry.

Interview conclusions and future developments

The construction sector in various countries is increasingly prioritizing sustainability, with an emphasis on circular economy practices. Despite diverse approaches and challenges, common themes and needs emerge:

- Resource Efficiency: All seven countries recognize the need to reduce resource consumption and waste generation. They are exploring strategies such as recycling, upcycling, and the use of recycled materials.
- Digitalization: Digital tools are essential for implementing circular economy principles. Technologies like BIM, IoT, and cloud computing are being used to track materials, monitor energy consumption, and optimize building performance.
- Collaboration: Effective collaboration among stakeholders is necessary for successful circular economy initiatives, involving collaborative platforms, data sharing, and stakeholder engagement.
- Policy Support: Governments are playing a crucial role in promoting circular economy practices through policies, regulations, and incentives.

Several factors drive the adoption of circular economy practices. The most powerful driver seems to be regulation and legal requirements, although specific circularity requirements or regulations are still lacking. Client demands significantly influence circularity decisions and sustainability in general, with an increasing demand for certifications like LEED or BREEAM. Government incentives also play a crucial role, primarily promoting the reduction of waste and the reuse of materials. Additionally, cost considerations are important, as the economic benefits of using reclaimed materials are highly preferred.

Countries are employing both immediate and future-oriented circular strategies in their construction sectors. Immediate impact is achieved through design for disassembly, waste minimization, and modular construction. At the same time, future-oriented approaches like detachable and adaptable designs are also employed, though legal challenges persist. The three most impactful and widely used circular strategies in interviewed countries are:

- Design for disassembly/assembly (Facilitating the future reuse of building components)
- Design for flexibility and adaptability (Designing buildings that can be easily modified or repurposed)
- Design with circular materials (Incorporating reclaimed or recycled materials into new constructions).

While awareness of circular economy practices is high, implementation varies significantly. Co-partnering and collaborative efforts are common, yet there remains a need for greater focus on circularity. The market for reclaimed materials remains small and challenging, despite numerous pilot studies and demonstration projects. Effective implementation of circularity in projects requires a structured process: gathering data on existing buildings and materials, evaluating which components can be reused, and developing new use plans based on this evaluation. This entire process demands continuous and robust collaboration among contractors, project owners, architects, and consultants. Regular interactions, workshops, and weekly meetings between stakeholders are essential to define evaluation criteria and plan for reuse.

Digital tools are crucial for advancing circular economy practices. Building Information Modelling (BIM) plays a key role by integrating product data and ensuring materials are accessible and traceable. Continuously updated digital twins of buildings help manage materials and lifecycle data effectively. To support the construction sector in achieving circularity, software development should focus on:

- Enhanced BIM Capabilities: Integrating comprehensive product data, including material lifespan, CO_2 footprint, and composition.
- Digital Twin Technology: Developing robust digital twin solutions for real-time updates and management.
- IoT and Sensor Technology: IoT sensors and devices can monitor energy consumption, occupancy patterns, and structural health, providing real-time data for informed decision-making.

- Material Passport and Supply Chain Management: These tools, connected to BIM models, track the origin, quality, and movement of materials, ensuring transparency and efficiency in the supply chain.
- Collaboration Tools - Cloud Computing and Collaborative Platforms: These tools enable seamless collaboration among stakeholders, facilitating the sharing of data, expertise, and resources.
- Standardization: Ensuring consistent data formats and standards for easy
  interoperability between different digital solutions.

Although the construction sector is still in the early stages of adopting circularity, progress is being made through collaborative efforts, regulatory support, and the integration of digital technologies. By focusing on these areas, especially in software development and collaboration tools, the industry can enable architects, engineers, and contractors to design and construct buildings that are both environmentally friendly and cost-effective.

4.2 Circular design cases in construction

This section will present a selection of several case studies from the countries represented by the interviewees in the previous section. The full list of case-studies and the circular strategies applied there can be found in appendix B. They range from residential buildings to office and commercial spaces. Some notable projects include the Resource Rows, which reuses bricks and waste wood, and the Circle House, which aims for 90% of construction materials to be reusable (both in Denmark). The most frequently used circular strategies in the researched cases are ‘Design with secondary materials’ and ‘Design for assembly/disassembly’. ‘Design for short use’, ‘Design symbiosis’ and ‘Design for energy efficiency’ also occur frequently.

Resource Rows, Denmark, 2019 (Architects Journal, 2019; Lendager Group, 2020)
Resource Rows is a residential area partly constructed by using materials from abandoned buildings. It consists of two rows of three-story terraced houses and two five-story apartment blocks, featuring a shared courtyard and roofscape with greenhouses made from recycled windows.

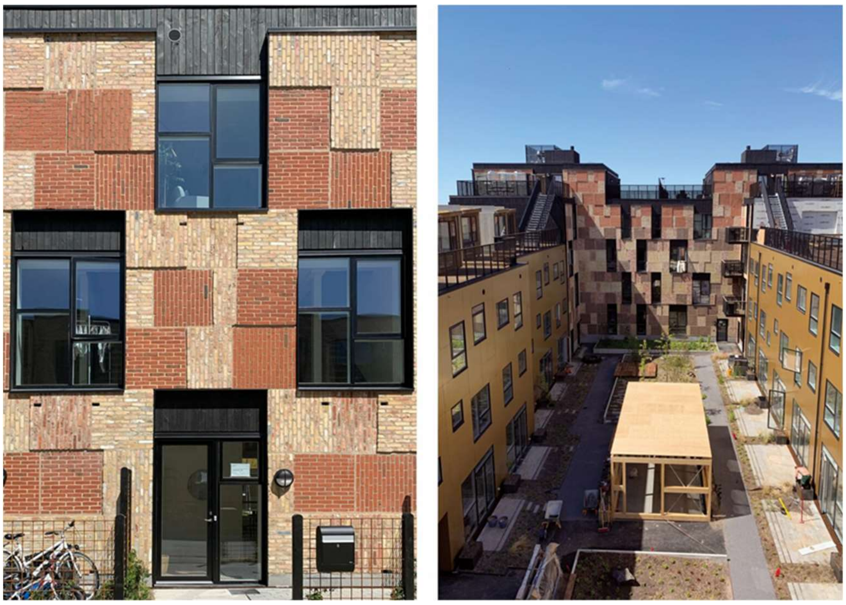

Figure 4-2. The Resource Rows project incorporates recycled brickwork panels, composed of cut-out segments from old brick walls, creating a colorful patchwork with a knitted texture.

Key features of the project are:

- **Design for adaptability/flexibility**: The design of the buildings allows for future modifications and repurposing, ensuring long-term usability and adaptability to different needs.
- **Design for assembly/disassembly:** Modular panels of recycled brickwork, fabricated from 3m² segments of old brick walls with mortar, enable easy assembly and disassembly.
- **Design with secondary materials:** The project incorporates panels of recycled brickwork sourced from three different buildings. Additionally, all exterior wood for window frames, terraces, and decking is made from recycled materials. Floors are constructed from off-cuts and waste from a high-spec flooring company, and a recycled steel bridge connects the two parallel terraces roof-to-roof across the courtyard.
- **Design for sharing**: The residents' greenhouse-like huts, made from recycled glass and window frames, foster communal living and shared spaces.
- **Design for energy efficiency**: The green roof is a potential space for growing up to four tons of fruit and vegetables a year. Rainwater is collected to help irrigate the green roof and to flush toilets.

The project's Life Cycle Assessment (LCA) considers both the embodied CO2 and the CO2 impact of operations throughout the building's life. Resource Rows has saved a total of 20 tons of CO2eq, or 29%, compared to the exact Resource Rows-type building, where upcycled products would not be used.

Circle House, Denmark, 2020-2024 (Concrete Centre, 2022; Tomorrow.City, 2024)

Denmark's first circular housing scheme, Circle House, is a research project that aims to develop a reusable precast concrete building system. The project is a large-scale demonstration initiative aimed at advancing circular construction methods and sharing the resulting knowledge across the industry. The project unites over 30 companies from different sectors of the construction value chain, fostering collaboration to drive innovation and promote sustainable building practices. By involving diverse stakeholders, the initiative breaks down industry barriers and encourages the adoption of circular principles throughout the construction process.

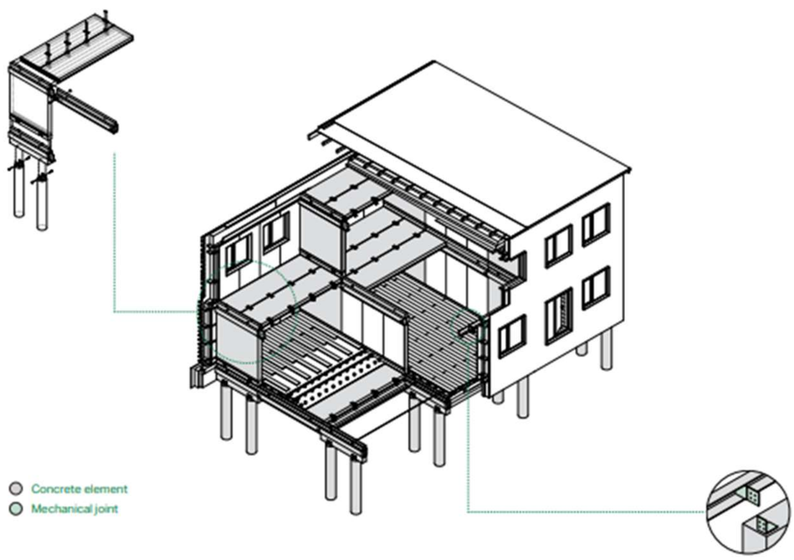

Figure 4-3. The project building has a higher degree of flexibility during its lifetime, and it consists of several building systems that will be reusable for other buildings and thus retain their value. © GXN

The key circular design strategies employed in Circle House include:

- **Design for assembly and disassembly**: The structural components are joined together using standard mechanical joints of bolts and screws, rather than cast-in-place cement-based mortar connections. This allows the system to be easily unscrewed and the components reused. The connections are cast with a lime-based mortar that can be pressure-hosed out to enable disassembly.
- **Design for adaptability and flexibility**: The precast concrete components can be configured and reconfigured in different ways, enabling the houses to be easily changed over their lifetime. The structural system is combined with a lightweight facade design, mounted on the exterior by using screws or mountings to allow reuse.
- **Design for component and material optimization**: The project has six different types of precast concrete components, including foundations, beams, and slabs, that are optimized for quick construction, disassembly, and reuse. The expectation is that 90% of the materials will be able to be reused.
- **Design for durability**: The facade cladding is attached to the wall using a wooden grid made from larch, a tree species known for its natural resistance to rot and mold. This feature ensures the

cladding's durability over time without the need for additional treatments.

- **Design with secondary materials**: Recycled tiles sourced from household plastic waste, sorted by color to create a variety of designs. Larch wood, known for its natural resistance to rot and mold, is used for the facade's wood grid, ensuring long-term durability without treatment. Recycled acoustic panels, designed for a lifespan of at least 75 years, can be reused multiple times in combination with a smart mounting system. Additionally, the façade-mockup features cork and old newspapers, algae for insulation, and repurposed tires for flooring.

In addition to its core objectives, Circle House integrates more sustainable practices throughout the project. One notable example is the use of digitized traceability, which connects each building element to a material passport containing detailed information about its components.

Arkadia - Largest recycled brick building, Australia, 2020 (DKO, 2019: The Local Project, n.d.)
The Arkadia development is a circular building project that focuses on ecological and social sustainability. The building is made from recycled bricks, and it focuses on minimizing waste and promoting sustainability through the use of recycled materials and efficient building systems.

Figure 4-4. Arkadia is made from recycled bricks that have been formed so that they create solar shading to the north and west with windows that allow cross ventilation while avoiding full summer sun penetration.

The project incorporates several circular design strategies:

- **Design with secondary and circular materials:** The project uses recycled bricks from another demolished building. The use of recycled bricks reduce waste and the demand for virgin materials.
- **Design for sharing:** The rooftop garden and productive gardens beds are designed to be shared among residents, promoting community engagement and social interaction. The building is designed to integrate with its surroundings.
- **Design for energy efficiency**: The project is designed to be fossil fuel free, with 100% electric power and renewable energy sources. The

building is also equipped with solar panels and a rooftop garden, which supports local urban agriculture and reduces the building's energy consumption. The building is made from recycled bricks that have been articulated with deep reveals, which create shaded areas on the facade. This helps to minimize heat gain from direct sunlight, reducing the building's cooling load and solar shading to minimize energy consumption.

Circular Building, UK, 2016 (Building Centre, 2016)
The Circular Building is a prototype designed to satisfy Circular Economy principles, with collaboration at its core. The project highlights the need for early and continuous collaboration between architects, engineers, material suppliers, and contractors to ensure that the building's components could be easily disassembled and reused. It also emphasized the use of digital tools to track materials and ensure their reusability.

Figure 4-5. The circular building prototype uses materials that can be reused, remanufactured, or recycled at the end of their life cycle. It has a low-voltage, off-grid electrical system, enabling future flexibility and easy maintenance.

The building incorporates several circular design strategies:

- **Design for assembly/disassembly**: The building uses a prefabricated construction technique with reusable clamp connections between the wall and recycled steel frame elements, allowing for easy disassembly and reassembly, reducing waste, and promoting the reuse of materials.
- **Design optimized shapes/dimensions:** The structurally integrated panel (SIPs) wall system is designed to minimize waste and optimize the use of materials.
- **Design for prefabrication**: The building is striving to maximize off-site fabrication.
- **Design with secondary materials**: The building incorporates reusable components, such as the recycled steel frame elements and the acoustic wall system made from recycled plastic bottles.
- **Design with circular materials:** The building uses sustainably sourced materials, such as heat-treated timber for cladding and decking.

Overall, the Circular Building in the UK is designed to minimize its environmental impact throughout its life cycle, from material sourcing to end-of-life disposal. The case emphasized the critical role of collaboration in achieving circular design in construction, the need for early stakeholder involvement, integrated processes, and the use of digital tools to manage and track materials. Developing better communication, standardization, and skill development were identified as key areas for improvement.

Kristian August gate, Norway, 2021 (Archello, n.d.)
Kristian August Gate demo building is a notable example of how circular design principles can be applied in practice, reducing waste, and promoting sustainability while maintaining the building's unique identity and value.

Figure 4-6. The façade panels used in the Kristian August Gate 13 project were sourced from a 35-year-old housing association building in Trondheim. The panels were carefully cut and adapted to match the dimensions needed for the project, resulting in 3,819 processed panels being delivered.

The key circular design strategies employed in Kristian August gate:

- **Design with secondary materials** is a key aspect of the project, as the building was renovated using materials from other projects, including old façade panels from Steni, concrete floor slabs from the R4 government building, and grille panels from the Tøyenbadet swimming center. The recycled materials were adapted to match the dimensions needed for the project, demonstrating design for adaptability.
- **Design for assembly/disassembly** is evident in the use of pre-fabricated components, such as the Steni façade panels, which were cut and adapted to fit the building. These panels were also designed with durability in mind, with a 60-year warranty, ensuring long-term sustainability.
- **Design for adaptability/flexibility:** The project demonstrates design for adaptability and flexibility through its planning and execution. The building's components were designed to be dismantled and reused during renovation or demolition, either locally or externally. And sealed walls between offices have been built such that every other wall is a fixed wall where technical elements have been installed in

accordance with the guidelines and the other walls are flexible walls. This approach ensures that the building can change function and use without significant material interventions, making it adaptable to changing needs.

Kvarteret Återbruket, Sweden, Started 2024 (Framtiden byggutveckling, 2024)
The project demonstrates the effective **use of secondary materials** in construction. The project incorporates a minimum of 50% reused materials, including 50-year-old hollow-core slabs, steel beams, and columns dismantled from an old IKEA department store.

Figure 4-7. To achieve large-scale recycling in construction, it is crucial to focus on the reuse of large structural components, as they have the most significant impact on the environment. However, this has proven to be challenging and not widely adopted in major projects thus far.

These secondary materials make up 80% of the load-bearing floors in the new 6,000 square meter apartment complex. By repurposing these components, the project highlights the potential for large-scale reuse in construction, promoting circular practices that reduce waste and environmental impact. The innovative use of secondary materials in the design of "Återbruket" showcases a more sustainable and eco-friendly approach to construction.

In previous research projects testing methodologies for these slabs have been developed, including compressive strength, durability, and tensile testing of reinforcing cables. The results have shown that the slabs can be reused for at least twice as long as today, with high-quality concrete and low degradation due to carbonation. To facilitate this process, a new standard has been developed, and structured processes are now available to ensure quality assurance. This approach has been cost-effective and has involved collaboration between various stakeholders, including NCC, RISE, and other partners.

Residential building, Bergen, Norway (Bellini et al., 2024)
The research of Bellini et al. (2024) presents a residential building case in Bergen, Norway. The case concentrates on the efficient implementation of

reuse and underscores the importance of collaboration in circular design within the construction industry. The successful implementation of reuse strategies depends heavily on interdisciplinary collaboration and structured data management.

Figure 3-8: The residential building before dismantling (source: Bellini et al., 2024)

Early and continuous collaboration among architects, contractors, and other stakeholders is crucial for the effective **reuse** of construction materials. By involving all parties from the project's inception, potential reuse opportunities can be fully identified and integrated into the design and construction process. This collaborative approach ensures that all stakeholders work towards a shared goal of sustainability. In this case the client and architects plan to incorporate reclaimed products into both commercial and residential spaces, such as apartments. Determining the optimal placement of reclaimed materials in the new building necessitates ongoing communication and cooperation among architects, clients, and contractors.

The case brings out the necessity of centralized data management to facilitate collaboration in circular construction. Digital tools (like Building Information Modeling and Material Passports) play a pivotal role in storing and managing information about construction products, enabling stakeholders to assess the reusability of materials. However, the practical adoption of these tools is still limited, emphasizing the need for a more coordinated effort to standardize and utilize digital platforms across the industry.

The research introduces a three-step process that relies on collaboration to ensure the success of reused products. This process begins with the collaborative collection of information, involving reuse mapping and documentation of existing structures. It continues with joint evaluations, where various stakeholders assess the environmental, technical, and logistical feasibility of reusing specific products. Finally, the collaborative planning stage addresses challenges like technical testing, logistics, storage, and ensuring the traceability of information.

Bellini et al. (2024) emphasize that effective collaboration across all stages of the circular design process— from data collection and evaluation to planning and market engagement—is essential for advancing the reuse of construction products and achieving sustainability in the construction industry.

4.3 Circular requirements transforming design operations

To assess whether adjustments to the design process are necessary when implementing circular design practices, a workshop was held with the LiveCol partners. The goal of the workshop was to gain a perspective on which circular strategies (see section 3.2) are most important, and after that to assess their impact on the design process. The latter goal was implemented by focusing on the types of information that should be shared between industry stakeholders in order to facilitate circular strategies.

The workshop started with a general introduction of the circular strategies, their purposes, and goals through the LiveCol conceptual framework. The framework served as introductory material for the participants who after that selected those strategies that they deemed most important. Then, these chosen strategies were linked to use-cases where different stakeholders' information needs were identified. The workshop ended with a discussion between the participants on the workshop findings.

Findings

The three most important circular strategies according to the participants were, 'Design for durability' (n=8), 'Design for assembly/disassembly' (n=8), and 'Design for adaptability/flexibility' (n=7) (see table 4-1).

Table 4-1: Most important design strategies as viewed by the participants (the higher the number, the more important the strategy). The last two strategies were not included in the circular strategy framework but were developed independently by the participants.

Strategy	n
Design for durability	8
Design for assembly/disassembly	8
Design for adaptability/flexibility	7
Design symbiosis	5
Design for component and material optimization	4
Design with secondary materials	3
Design for accessibility	3
Design with modularity	3
Design for prefabrication	3
Design with circular materials	3
Design for layer independence	2
Design for energy efficiency	2
Design for sharing	2
Design for optimized shapes/dimensions	2
Design for standardised solutions	1
Design for short use	1
"Design for use"	1
"Optimization of systems with different lifecycles"	1

These three strategies along with the strategies: 'Design with circular materials', 'Design symbiosis', and 'Design for prefabrication/modularity', were then linked to 5 different use-cases through design canvases where the different types of information needs for each stakeholder were identified (see tables 4-2 – 4-6).

Table 4-2: Design for durability canvas for the 'information needs in the structural frame durability' use-case. Representing the design for durability strategy.

Strategy	Design for Durability		
Use-Case	Durability of the structural frame		
Stakeholder	**Information needs**	**Information source**	**Information to be linked to the digital model**
Architect	Information about the physical properties of components	-	-
Structural Engineer	Connector design – adaptable and dismountable components	Collaboration between architect and structural engineer	How and at which points components may be attached to the structural frame
HVAC Designer	Space reservations for the most important components keeping in mind future functional building changes (high enough ceiling height usually enables later changes).	-	-
Client (Client demands are the first scope boundaries)	What is the client paying for? What lifecycle benefits will arise? Lifecycle maintenance plan (logbook) Use of lifecycle data	-	Age of components and their maintenance requirements Subscription model would allow following up and benefitting from continuous data gathering through sensors (condition, moisture, fatigue)
Remarks	- Data should not have to be moved in order for it to be usable - Good tools and data won't solve the issues by themselves, people need to actively use those as well.		

Table 4-3: Design for adaptability, design for assembly/disassembly canvas. Information needs in 'Change of purpose of spaces' use-case. Representing the design for adaptability and the design for assembly/disassembly strategies.

Strategy	Design for adaptability, design for assembly/disassembly		
Use-Case	Change of service areas/change of purpose of use of space (e.g. from cubicle office to open space)		
Stakeholder	**Information needs**	**Information source**	**Information to be linked to the digital model**

Architect	Information about the building's service areas. Space modeling.	From the HVAC designer, currently often pdf. Service area diagrams from the building owner, can be found through the HVAC designer.	More efficient utilization of the space model by also modeling the service areas in it.
Structural Engineer	Principally, the structural engineer does not participate in the design of service areas but does participate in structural changes.	-	-
HVAC Designer	All HVAC designs for existing space. In the editable form of the original model.	From the design offices (not necessarily ready to share plans, depends on contracts)	-
Client (Client demands are the first scope boundaries)	-	-	-
Remarks	- Changes in the service area lead to adjustments in HVAC component requirements, highlighting the differing needs of open office spaces compared to cubicle offices. - The architect needs to understand the current usage of the space and gather information about the building's premises as a model. The HVAC designer is responsible for creating the service area diagram, which provides essential information for the space model. Existing service area diagrams should be obtained from the client through the HVAC designer. - The role of structural design only in the change of structural systems, what is the connection to the data model? - The HVAC designer must either create a new model from scratch or request existing models from previous designers. Generally, the transfer of information in this field is hindered not by technical issues, but by contractual obligations, trade secrets, and competing incentives.		

Table 4-4: Design with circular materials canvas. Information needs in 'building component reuse' use-case. Representing the design with circular materials strategy.

Strategy	Design with circular materials		
Use-Case	Building component reuse		
Stakeholder	**Information needs**	**Information source**	**Information to be linked to the digital model**
Architect	BIM objects of the construction parts of the building to be demolished - Original product information on reusable parts	The broker of demolition parts produces models of the parts they are redistributing	The objects contain dimensioning and load information
Structural Engineer	Original product information on reusable parts Certifies the validity of the still-to-be-used structure	-	-
HVAC Designer	Technical data of reusable parts - commissioning cannot be done without	-	-
Client (Client demands are the first scope boundaries)	What does it cost? What life cycle benefits are created? Knowledge of the eligibility of construction parts	From the designers Based on information from the dealer of demolition parts	-
AI	Searches and offers suitable building parts from libraries/marketplaces of circular economy materials	-	-
Remarks	-		

Table 4-5: Design symbiosis canvas. Information needs in 'use of retrieved components in a new building' use-case. Representing the design symbiosis strategy.

Strategy	Design symbiosis		
Use-Case	Use of retrieved components in a new building (CLT element, hollow slab, steel structures, etc.)		
Stakeholder	**Information needs**	**Information source**	**Information to be linked to the digital model**
Architect	Requirements Dimensions, geometries, visual and technical characteristics CO_2 numbers after retrieval Price	Requirements from the customer or authority CO_2 figures from the redistributor Technical requirements and price from the supplier of demolition parts (broker/owner)	Dimensions, geometries, visual and technical characteristics CO_2 figures
Structural Engineer	Dimensions CO_2 figures after retrieval Requirements Material information (strength calculations)	Supplier of demolition parts Requirements from the authority	Dimensions, geometries, visual and technical characteristics CO_2 figures
HVAC Designer	-	-	-
Client (Client demands are the first scope boundaries)	-	Supplier of demolition parts	CO_2 figures
Urban Miner	Storage conditions Need for processing (surface treatment, need for fire protection, etc.) Total number of parts Demand and forecasts Original EPD?	Original designer	-
Remarks	-		

Table 4-6: Design for prefabrication/modularity canvas. Information needs in 'bathroom module' use-case. Representing the design for prefabrication strategy.

Strategy	Design for prefabrication/modularity		
Use-Case	Bathroom module		
Stakeholder	**Information needs**	**Information source**	**Information to be linked to the digital model**
Architect	What are the design boundary conditions? Design instructions from the factory supplier > the problem is at which stage the supplier enters the process. Usually design is on a rougher level in early stages.	From the selected product parts supplier	Connection to the factory's ERP-system
Structural Engineer	Design and plans from the architect	-	-
HVAC Designer	Connection point locations. Responsible for the technical functionality of the bathroom, approves the plans	-	-
Client (Client demands are the first scope boundaries)	Selection of modules and bidding	-	-
Urban Miner	The benefits of the factory environment vs. the construction site	-	-
Remarks	Implementation of the bathroom module - For the architect, information about the limitations of the product, the design is made on a general level - HVAC design fundamentally relies on the architect's plans, while the HVAC designer is tasked with designing the connection points to the technical infrastructure. Ultimately, the responsibility for the system's functionality lies with the HVAC designers. - Structural design produces most of the design boundaries		

In the concluding workshop discussion, participants mentioned that the collaboration between stakeholders is the most important part of circular construction projects. Also the client plays an important part in the feasibility of circular solutions as they set the boundaries that either allows or excludes certain strategies. There were some questions as to how to reach practical implementation of circular strategies. One of the challenges highlighted is the uncertainty of future demands. How can we incorporate this uncertainty into today's building designs? In that regard, participants mentioned the expectation that new business models and/or stakeholders might be necessary in the construction industry to facilitate circularity. As an example, it was mentioned that demolition companies could for instance serve as brokers between old and new buildings. It was also found that there is a need to think differently about construction in general and focus more on building according to society's needs in order to reduce waste. A role for prefabrication (HVAC) and AI to connect different parts of the value-chain was also identified.

For digital models in particular it was thought to be beneficial to start steering and monitoring circularity as soon as possible in the design phase. In the models themselves, complementary material data, as well as maintenance and packaging information should be linkable throughout the lifecycle of the building. Also, the reusability requirements could be linked to the components in question. A question that was raised by the participants is whether the model should include logistics data as well, and if so in what manner this would need to be available. All in all, regardless of data protection issues, the digital building model should make it easier for designers to reuse materials and components instead of using new materials and components. One important topic raised by the participants is that current contracts between stakeholders might hinder the adoption of the needed data and information in the digital building model throughout the building lifecycle. Meaning that i.e., even if it would be technically possible to add the necessary data and information, current industry practices would not allow for this to function. Finally, it was established that digital building models should be stored according to certain systems and/or protocols that would allow for retrieval of the data by other stakeholders at any point in the building lifecycle.

Analysis of results

To translate the findings from the workshop to implications to the design and modelling context, an analysis was made where the findings are offset against the ISO 19650 (BIM Management) process description (see figure 4-8). This is done for two categories; (1) process management requirements, and (2) data requirements. Also several business and development opportunities were identified through this analysis. The requirements are described below for every stage of the BIM Management process. If a certain stage is not described, this means that there were no workshop findings pointing towards design process requirements for that stage.

<u>Process management requirements</u>

1. Strategy and need
- Build wisely and according to the established needs, prevent waste
- Overcome possible issues already in the contracts, not only in the software
- Building models need to be flexible and updateable, throughout the life-cycle
- The client determines the to be applied Circular Strategies

2. Execution
- Determine the archiving protocol

- Link object/component data with additional and maintenance data through live databases (note that there are currently no standards for this, need to be developed)
- Solve possible data protection issues that might prevent later reuse
- Determine appropriately scoped course of action

3. Delivery
- Determine and describe the methods of cooperation between designers

4. Brief
- Model space reservations for the most important building components, to ensure possibilities to change the building (purpose) later in the life-cycle (e.g., sufficient ceiling heights)
- Use best-practices (improve efficiency): use standard and/or pre-fabricated products

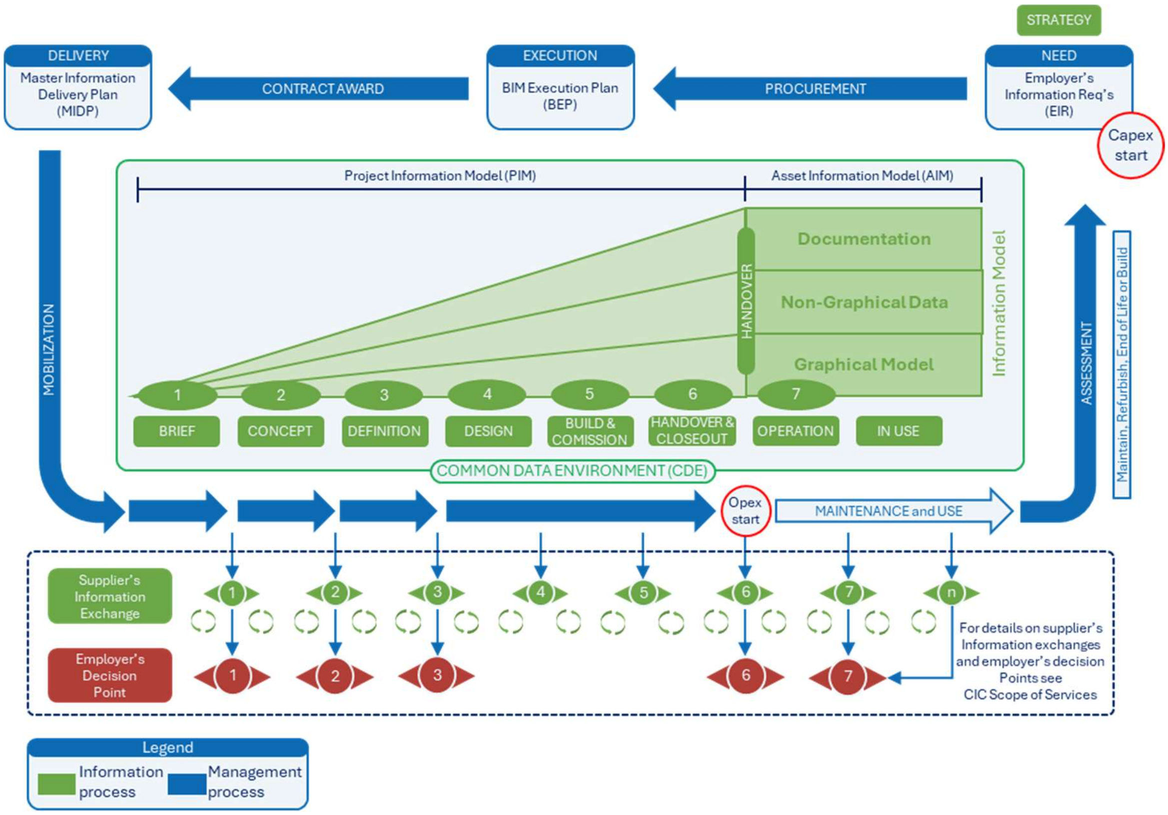

Figure 4-8: ISO 19650 process description

5. Concept
- Determine and describe the design principles and boundaries

6. Design
- Model service areas of different components, to ensure feasible building changes later in the life-cycle

7. Build and Commission
- Verify that the building is constructed as designed, and ensure that the as-built models precisely reflect the physical reality

8. Assessment
- Search and offer suitable circular building components in libraries and marketplaces. Currently, these components are unavailable and need to be developed.
- Ensure that the component designated for reuse is in suitable condition. Note that there are currently no established standards for this, which need to be developed.

<u>Data requirements</u>
The data requirements are explained with the help of the ISO19650 process description (see figure 4-8) in four categories: (1) currently available in graphical model, (2) currently possibly available in graphical model (depending on building age), (3) currently available in documentation / as non-graphical data, and (4) currently not available in any of the above categories.

1. Currently available in graphical model
- Requirements
- Dimensions, Geometry, Visual & Technical properties

2. Currently possibly available in graphical model
- Digital models of the to be dismantled building components
- Location of the 'connector'-points
- Measurement and transportation information of components
- Technical information of components (e.g., surface treatment, fire rating, etc.)
- Designated building service areas (HVAC)
- HVAC designs in adjustable (original) data format

3. Currently available in documentation / as non-graphical data
- Component requirements
- Original product certificates (CE, DoC)
- Material information (e.g., technical strength)
- Technical specifications (HVAC)
- Component age and maintenance information
- Logistics and transportation information

4. Currently not available in any of the above categories
- Carbon Emission figures after 'harvesting' components
- Connection points between elements
- Needed storage conditions for different components
- Demand and supply of components
- Original product EPD's

Signaled business and development opportunities

Further analysis of the workshop findings reveals five different opportunities. The first one is the development of a construction system that allows future changes to be made to the building. The second is the use of AI to gather data from different sources and projects (e.g., sales platforms and component libraries), to facilitate circularity. The third is the use of prefab HVAC components that can be exchanged without replacing whole systems (coupled with the use of digital models for information distribution). The fourth is the need for new industry stakeholders, as e.g., demolition companies might act as middlemen in material and component redistribution, but principally only have knowledge of demolition and crushing. The fifth and final opportunity is to find a solution for the (temporary) storage problem when redistributing construction materials and components.

Concluding remarks

The workshop, its findings and analysis offered insights into process management and data requirements for the circular design process. Some of the key findings for LiveCol are:

1. Linking objects & components with live databases
2. Search and offer objects & components in libraries and markets
3. Quality Assessment (QA) & Quality Control (QC) of to be reused components
4. Enhance digital availability of certain data types & establish protocols for (currently) unavailable data

All the information types mentioned in those four elements need to be delivered by various stakeholders. In other words, increased collaboration is needed for circular design to function.

5 Discussion

The findings from this report seem to indicate that designing buildings with circularity in mind is essential for sustainable construction and future renovations. Across the interviews, case studies, and workshop several similarities and gaps were revealed in the application of circular design. To start with, the role of the client and regulation were identified as the main drivers for circularity in the construction industry. Even though the sample size of this research was small in terms of the number of interviews, case studies and workshops, these two drivers have also been identified in earlier research (Çetin et al., 2020; Chen et al., 2022; Hart et al., 2019; Kanters, 2020).

Second, from the interviews, case studies, and workshop the strategies 'Design for disassembly/assembly' as well as 'Design for flexibility and adaptability' were seen as either most important or mentioned most frequently. For both the interviews and case studies also 'Design with circular materials' and 'Design with secondary materials' were covered frequently. In material selection, prioritizing durable, reusable, and recyclable materials, particularly reclaimed or repurposed ones, helps reduce the need for raw material extraction and focuses on materials with low environmental impact and long lifespans. To ensure longevity, buildings can be designed for adaptability and ease of modifications and upgrades. Implementing flexible layouts, demountable partitions, and accessible service areas facilitates future changes without major demolition.

Examples of these strategies from the case studies are salvaging bricks from abandoned buildings (Resource Rows, Denmark), or incorporating at least 50% reused materials (Kvarteret Återbruket, Sweden). Circle House in Denmark uses standardized mechanical joints, allowing easy unscrewing and reassembly, while the Circular Building in the UK employs reusable clamp connections. These features promote adaptability and reduce waste during a building's lifecycle. Projects like Arkadia (Australia) prioritize ecological sustainability. By using recycled bricks and efficient building systems, they illustrate that circular design can maintain aesthetics without compromise. Sustainability and visual appeal can cooperate. Kristian August Gate (Norway) exemplifies this balance, it follows circular design principles while maintaining architectural quality. The focus on these strategies aligns with current circular economy research in the construction where the focus has almost exclusively been on the reuse-goal (R3) which is closest to the strategies identified here (Yang et al., 2022).

Third, the interviews highlighted an increased need for collaboration, as well as a need for increased adoption of digital tools that promote; (1) enhanced BIM capabilities, (2) digital twin technology: Developing robust digital twin solutions for real-time updates and management, (3) IoT and sensor technology, (4) material passport and supply chain management, (5) collaboration, and (6) standardization. From the Circular House and Residential Building case studies, it was found that integrating life cycle thinking into design decisions optimizes resource use and minimizes waste. Also, the importance of engaging stakeholders early in the design process to ensure alignment with sustainability goals and addresses future renovation needs efficiently was identified in the latter case.

Interestingly, apart from those two buildings the case studies did not reveal collaboration needs or give an idea of where and how digital tools could be applied. In general the focus of the case-studies seems to be more on the (re)used materials and physical representation of the buildings, not so much on the needed processes guiding circular design. The workshop did give a more in depth view of the information and collaboration needs between different stakeholders. Even if the workshop findings are limited to a single workshop, it is interesting to see that most of the identified information types were also identified in a Design for Disassembly-context by Uotila et al. (2024).

Fourth, findings from the interviews point towards the difficulty to scale circular solutions in the construction industry. The workshop participants suggested that new stakeholders are needed in the industry in order to facilitate circularity and thus circular design. The case studies as well as the interviews show that in several countries (small scale) material brokers, linking reclaimed materials with new buildings and stakeholders have emerged. However, also for these solutions the difficulty of scaling up was mentioned. Utilizing prefab and modular construction methods, where components are manufactured offsite and assembled onsite were also mentioned in the workshop and one of the case studies, as they reduce waste, save materials, and enhance energy efficiency. However, workshop participants also pointed out that the reasons for the lack of circular uptake may not be technical but reside at least partially in contractual issues between stakeholders. This observation, coupled with the one that so far only a limited amount of strategies and goals have been researched and applied in the construction industry, give an indication that for future efforts it might be worthwhile to check the scalability and legal conformity of circular solution before diving too deep into technical solutions.

6 Recommendations for LiveCol

Based on this report further project developments may consider circularity in the following ways:

Stakeholders

- With or without technology, collaboration and discussion about the inclusion of circular targets should take place as early in the process as possible.
- Any development should take the perspective of the client into account.

Strategies

- Be aware that the circular strategies that have so far been most important in the construction industry are:
    - Design for Disassembly / Assembly
    - Design for Adaptability / Flexibility
    - Design with Secondary / Circular materials
- Check the scalability potential of the chosen strategy and related solutions and consider other strategies in case the most important strategies do not offer this potential.

Technology

- Any technology development that aims to incorporate circularity should try to include the following functionalities:
    - Integrate comprehensive product data, including material lifespan, CO_2 footprint, and composition into digital models
    - Ability to linking objects & components with live databases
    - Ability to search and offer objects & components in libraries and markets
    - Ability to contain QA & QC data of to be reused components
    - Enhance digital availability of certain data types through standardization & establish protocols for (currently) unavailable data
- The following tools and technologies might be especially helpful in facilitating circularity in the construction industry:
    - IoT and Sensor Technology: IoT sensors and devices can monitor energy consumption, occupancy patterns, and structural health, providing real-time data for informed decision-making.
    - Material Passport and Supply Chain Management: These tools, connected to BIM models, track the origin, quality, and movement of materials, ensuring transparency and efficiency in the supply chain.
    - Collaboration Tools - Cloud Computing and Collaborative Platforms: These tools enable seamless collaboration among stakeholders, facilitating the sharing of data, expertise, and resources.
    - Marketplaces: These platforms could provide a way to link supply and demand of secondary and circular materials. The inclusion of AI in such platforms could increase the efficacy of handling the vast amounts of related data.

7 Conclusions

Sustainability is finding its way into the operating environment of the construction industry through increasing regulation and voluntary initiatives on a global, European, and national level. Within the wide range of sustainability perspectives, circularity has become a focal research and development point in the construction industry. However, circularity has not become commonplace in industry practices. Many general barriers and enablers to the adoption of circularity in the industry have been mentioned in literature, but practical insights into how circularity can be included into the design process are less frequently described.

This report has shed some light on the possibilities and consequences of including circularity into design processes by establishing a circular strategy framework, conducting interviews, case studies and a workshop. From those efforts it has become clear that there is not one single way of approaching circularity in design processes. Instead, different and multiple strategies can be applied at the same time, leading to different processes and outcomes. That being said, 'Design for Disassembly / Assembly', 'Design for Adaptability / Flexibility', and 'Design with Secondary / Circular materials' are the most followed strategies in the construction industry.

The need for early collaboration between stakeholders on circular topics in projects has also become apparent. It is also clear that there for this collaboration to be effective, certain types of information and data should be available for different stakeholders. Currently this data and information is not always (easily) available. This report has given some indications where technology might aid in facilitating collaboration by supplying stakeholders with the information, data, tools, and platforms needed. At the same time, stakeholders should be aware that the unavailability of certain information and data in the process is not the result of failing or missing technology, but rather of legal or business limitations.

In using the results of this report caution should be exerted, since even if the discussion pointed towards connections of the report's findings with literature, the basis is still slim with a limited amount of interviews, case studies, and workshops. Therefore, the validity of the report's findings should be re-established in case of applications in follow-up projects and developments. Further research into the inner workings of circular construction design processes would be warmly welcomed by the authors.

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Appendix A: Interview questions

General

1. How important are the following aspects when **defining the term "sustainable construction"** in your country? (1=not important, 5=very important)
    a. Carbon footprint 1-5
    b. Resource efficiency 1-5
    c. Sharing 1-5
    d. Energy efficiency 1-5
    e. Circular materials 1-5
    f. Something else, what? 1-5

2. What **sustainability targets** or topics are emerging currently in building design?

3. Is there **specialized consultant** in design teams for sustainable and circular design?

Drivers for circular economy in design

4. What are the **drivers** for applying circular economy targets and methods in design practices?

5. Some circular strategies are future oriented like detachability, movability, etc. And some strategies have immediate impact like recycled materials etc. **How are these weighted and realized in your country?**

Circular design

6. In your opinion, what are the **three most impactful circular strategies** presented (slide 5) in building design? You can also suggest other strategies.

7. What are the circular economy **actions in reality**?

8. **Is there a process** for implementing circular design? (e.g. communication and collaboration) What kind?

9. Is there any **communication or cooperation between** contractors, suppliers and designers, regarding circular economy?

10. Do you have any examples of cases where circular strategies are adopted in design?

11. Are there **circular solutions service providers or other business** within circular economy in construction in your country? Please specify?

Future development

12. What are expected **further developments** in the domain?

13. How do you see **digitalization serving circular economy**? Any BIM-solutions?

Appendix B: List of case-studies and applied strategies

Circular strategies used in democases	Design Strategy															
	Design for adaptability / flexibility	Design with modularity	Design for assembly/ disassembly	Design for durability	Design for accessibility	Design for layer independ ence	Design symbiosis	Design for short use	Design with secondary materials	Design with circular materials	Design with standardis ed solutions	Design for component and material optimisation	Design optimised shapes/ dimensions	Design energy-efficiency	Design for sharing	Design for prefabric ation
Resource Rows, Denmark	X		X						X					(X)	X	
Circle House, Denmark	X		X	X					X			X				
Upcycle Studios, Denmark	X								X					X	X	
TRÆ, Circular Carbon Bank, Denmark									X	X						
UN17 Village, Denmark				X					X					X	X	
Quay Quarter Tower, Australia/retrofit demo				X			X		X					X		
Arkadia - Largest recycled brick building, Autralia									X					X	X	
The circular buildings, UK			X						X	X			X			X
Temporary courthouse, Netherlands			X					X					X			
Cargo building, Netherlands							X		X							
Liander head office, Netherlands			X		X		X		X	X				X		
Kristian August gate, Norway	X		X						X							
Climate smart office - Corem, Sweden							X		X							
Temporary market hall		X	X					X		X						
Kvarteret Återbruket, Sweden, Started 2024									X							
Residential Building, Bergen, Norway									X							
	4	1	7	3	1	0	4	2	14	4	0	1	2	6	4	1

LiveCol

LiveCol is a BusinessFinland funded co-innovation project that will develop and validate new methods and tools to enable design and construction teams to collaborate through real-time 3D data sharing and communication in virtual 3D environments.

The aim is to move from differentiated and periodically coordinated design towards parallel, open, and up-to-date design information management, supported by 3D tools and associated communication services. The objective is a systemic change of approach, with the help of technology, from the production of design documents to real-time collaborative design.

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