White paper

Circular construction in Switzerland – Where is innovation happening today?

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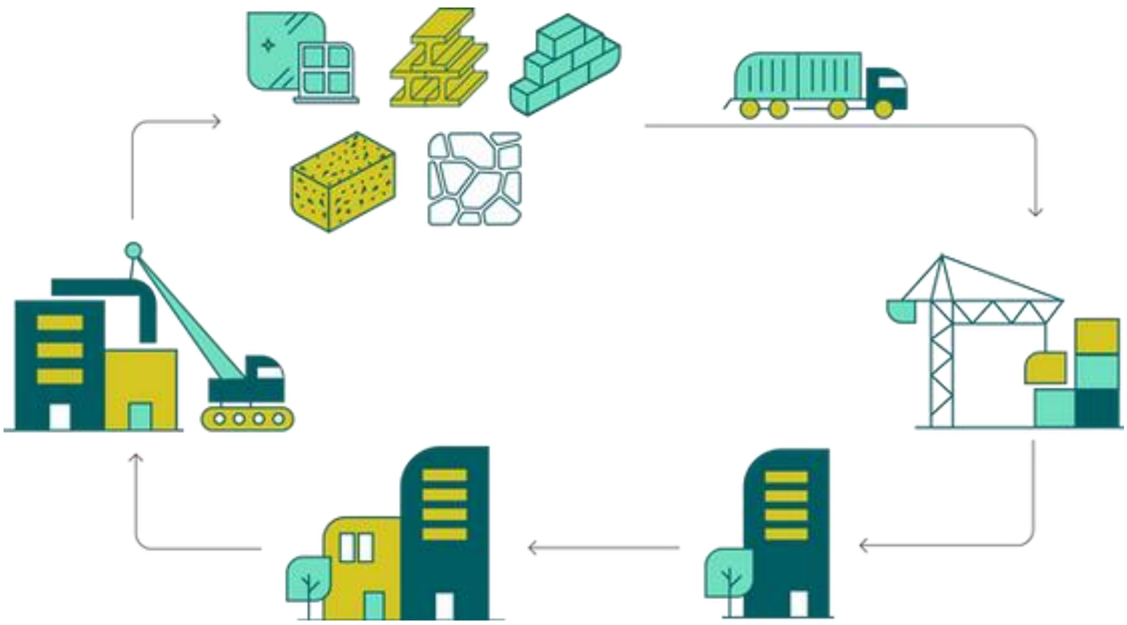


Source: What is circular construction? | Circuit (circuit-project.eu)

1. Status and innovation in the AEC industry

While the building industry plays a fundamental role in societies' standard of living and economy, it currently also has a tremendous environmental impact. This impact consists of both energy and material consumption, leading to high greenhouse gas emissions and waste streams. In 2020, the sector produced 11.7 Gt energy-related CO_2 emissions, which corresponds to 37% of global energy-related CO_2 emissions of that year. This 37% is divided into 27% occurring in the use phase, and 10% in the manufacturing and building phase (United Nations Environmental Programme, 2021). At the same time, the industry's material demand is at a high level and growing rapidly: tripling from 6.7 billion tons in 2000, it reached 17.5 billion tons in 2017, despite demand for building materials stabilizing in Europe and North America (Huang et al., 2020). Correspondingly, the waste streams of the industry amount to a large proportion of overall solid waste. In the European Union (EU), construction and demolition waste (CDW) accounts for approximately 60% of total solid waste (Robinson et al., 2021). This percentage is even higher in Switzerland: with 74 million tons per year, CDW accounts for 84% of solid waste in the country (FOEN, n.d.).

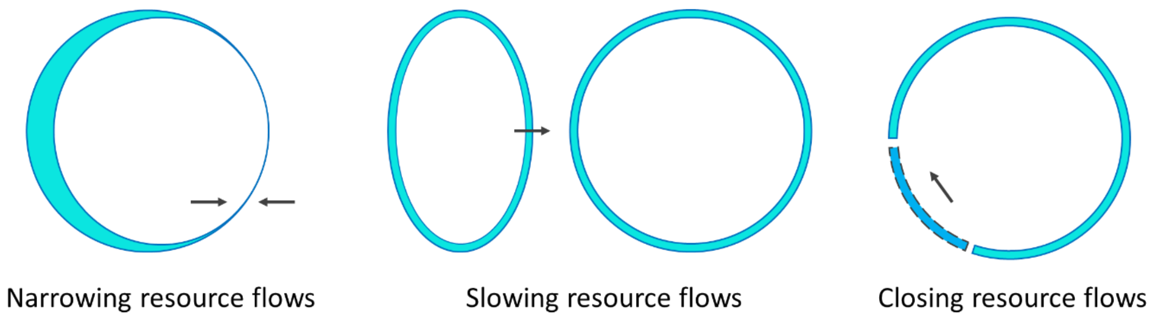
This size of impact indicates that a significant change in the building industry is necessary to reduce material and energy consumption in order to reduce GHG emissions and other environmental impacts. In this context, and especially considering the large material footprint of the building industry, the "take-make-waste" approach of the currently dominating linear economy has been criticized. Instead, the shift towards a circular economy (CE) has been advocated (Benachio et al., 2020). The Ellen MacArthur Foundation (2021) defines the concept of circular economy as: "*Looking beyond the […] current extractive industrial model, the circular economy is restorative and regenerative by design. Relying on system-wide innovation, it aims to redefine products and services to design waste out while minimizing negative impacts*." Political ambitions both on international and national levels underline the necessary of a transformational shift. The EU Circular Economy Action Plan includes initiatives along the entire life cycle of buildings from increasing the use of excavated soil to adaptability of buildings and material recovery targets. Switzerland initiated the parliamentary initiative 20.433 "Strengthening the Swiss circular economy" and the city of Zurich included the circular economy in its constitution in 2022.

While the importance of shifting to a circular and sustainable construction industry has been widely accepted by actors in academia, policy, and industry alike, implementation appears to be lagging. This has been linked to a range of organizational, economic, technological, and political barriers (e.g., Mahpour, 2018; Marchuk, 2020; Nordby, 2019; Selman & Gade, 2020). In this context, it is also important to consider the characteristics of the construction industry, differentiating it from other industries, which includes its size, fragmentation, competitiveness, and a slow rate of innovation. Globally, the construction sector contributed 13% of the global Gross Domestic Product (GDP) in 2020, and is expected to reach 13.5% in 2030 (Robinson et al., 2021). In Switzerland, the construction industry accounts for about 15% of GDP, and employs around 333 000 people (PwC, 2020). It consists of around 50 000 companies, whereby a large share are micro-enterprises with less than ten employees and companies are usually highly specialized and carry out only part of the construction project. This leads to fragmentation of the construction supply chain (Wollny & Bundesamt für Statistik BFS, 2022). Despite of the size of the sector in the Swiss economy, it is a very competitive industry, as the offer for construction products tends to be larger than the demand. This is combined with a low level of innovation, which is also aggravated by the lack of financial margins and supply chain fragmentation. This slow uptake of innovation leads to little differentiation based on products and processes, which in turn creates fierce competition based on prices and small cost margins (PwC, 2020).

In this context, innovations in the fields of sustainability, digitization and technology are perceived as crucial opportunities for differentiation (PwC, 2020)—three topics that are closely linked to CE, but that have been difficult to adopt by the construction industry (e.g., Bock, 2015; Kivimaa & Martiskainen, 2018; Li et al., 2019; Regona et al., 2022). This shows that innovation related to CE is not only necessary from an environmental perspective but offers great potential to industry actors. Further, there is a need to support and drive its adoption by bridging the gap between research, public sector and industry, and facilitation open innovation and the creation of radical ideas between various actors.

2. Circular strategies in construction

There are different intersecting approaches for clustering and the hierarchization of circular strategies. In business model and design strategies, the terminology of slowing, closing and narrowing resource flows are used (Bocken et al., 2016). "*Narrowed flows*" encapsulate resource efficiency with the decreased use of resources, *"slowing*" captures the prolonged use of products, while "*closing the loop*" facilitates the cycling of resources after their service. Potting et al. (2017) established a hierarchy of available circular strategies, known as R-strategies for reduced resource consumption. The concept provides a framework (see Table 1) to guide priorities of resource management options. The scale advocates options for increased resource preservation and spans from 'reduce' at the top to 'recycle' at the lower end of the order. Researchers mainly refer to the circular strategies as R-strategies (Nasr et al., 2018) or value retention processes (Haupt & Hellweg, 2019). These circular strategies facilitate the adherence to cradle-to-cradle thinking, which is the design of materials and products in a way that at the end of their life, it can be reintroduced into a new product. Hence, the goal is to phase out waste and keep resources in a cycle.



Transferring the hierarchy of R-strategies to the construction industry derives examples of circular construction practices. These strategies can be applied on their own or in combination, on different levels of application in construction projects (material, component and building) and are at different readiness levels (theoretical, experimental and consolidated) (Eberhardt et al., 2022). On the material level, commonly used building materials by quantity in the EU 28 countries in 2020 are aggregates, structural clay, cement, limestone, steel, timber, whereby according to the highest GHG emission, the following materials lead the order: cement, steel, limestone, and structural clay see Fig. 2 and 3 (Robinson et al., 2021). Other important material share are insulation materials, as their proportional environmental impact in the Swiss context is expected to increase in the following years. This is due to a decline in new constructions and increase in renovation, leading to a decrease in the use of materials such as bricks and concrete, but an increase of the use of insulation materials which are required for building envelope renovations. Heerlen & Hellweg (2018) expect insulation materials to be the material with the highest environmental impact by 2035. In addition, insulation materials were treated with toxic flame retardants until a few years ago, which means that much of the insulation materials in the existing building stock is not recyclable and will have environmental impacts upon disposal (Heeren & Hellweg, 2018).

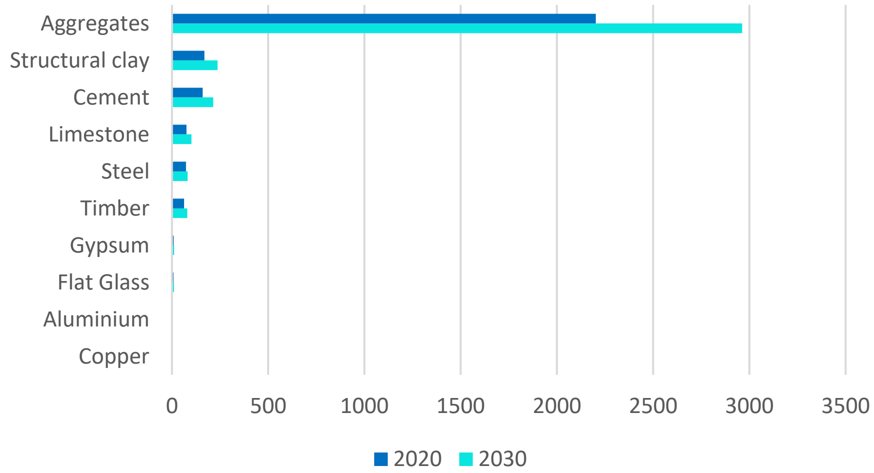


Figure 1. EU28 construction materials volumes 2020 and 2030 (Mn tonnes)

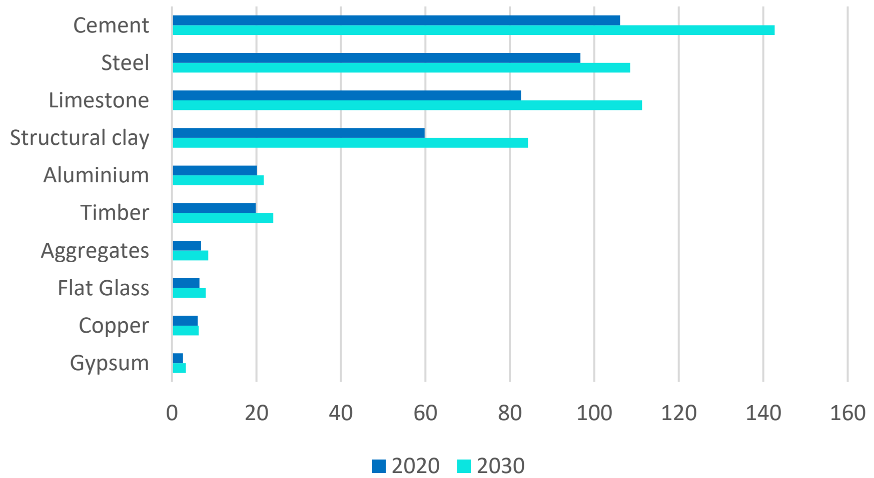


Figure 2. EU28 construction materials GHG emissions 2020 and 2030 (Mn tonnes)

Smarter product use and manufacture (“narrowing resource flows”)

In order to reduce the demand for building materials, the following CE strategies focus on using resources in the most efficient way. As such, the aim is to fulfill the same functions while reducing materials used, by rethinking how buildings are used, and cut down unnecessary use of materials.

Refuse: As refuse strategies would refer to abandoning the function of a construction (i.e., fulfilling space demands) altogether or fulfilling it with a completely different product, refuse strategies are hardly found in the building industry since their function is essential and there is no replacement product.

Rethink: Use of buildings can be rendered more intensive through sufficiency strategies (i.e., smaller dwelling sizes), and shared spaces, such as shared dwellings, but also shared office or study spaces. Multi-purpose or adaptable buildings allow for a more intensive as they can fulfill more types of functions, either for one or multiple users, such as multi-purpose neighborhood centers or home offices. These rethink strategies would ultimately lead to a reduced floor area per capita, which in turn reduces material and energy demand. The current trend of increasing floor area per capita, however, indicates that these strategies are not widely adapted (Hertwich et al., 2020).

Reduce: Resource use per product unit can be reduced through lightweight design, substitution with less environmentally harmful materials, substitution with renewable energy, and optimization of the logistics network. Lightweight design is often possible without compromising on functionality and safety, reducing the demands for steel and concrete for instance (Milford et al., 2013; Moynihan & Allwood, 2014). However, their wide adoption is not yet clear. Substitution with materials with a lower lifecycle impact have gained increased interest in academia and practice over recent years. Materials in the focus are, for instance, wood replacing steel and concrete (Heeren et al., 2015; Sandin et al., 2014), alternative materials to aggregates or cement in concrete (Choudhary et al., 2020; Pranav et al., 2020; Singh & Middendorf, 2020), or alternative insulation materials (Bumanis et al., 2020; Crini et al., 2020). The use of wood has become increasingly popular in Switzerland since 2010, as indicated by a demand increase of 20%. Nonetheless, its use on proportion to concrete and steel remains small (Schweizerischer Baumeisterverband SBV, 2021).

Extend lifespan of product and its parts (“slowing resource flows”)

The actual lifespan of buildings is usually much shorter than their potential lifespan. This is often due to changing needs of their users rather than physical deterioration, or different degrees of durability between building components, meaning that some could last for 75 years, while others need replacing after 20 years. Combined with the fact that buildings are constructed in such way that makes it difficult or even impossible to replace or repair only specific parts, this often leads to demolition of the whole building long before the most of it has reached the end of its lifespan (Debacker & Manshoven, 2016). The following CE strategies aim to prevent this and keep buildings and building components in use for a longer time.

Reuse: When a building does not fit the needs of its users anymore, instead of demolition, it can be continued to be in use by a different user with different needs. On a component level, certain building products can be reused in their original form in a different building, for instance bricks, window frames or structural elements. However, it is difficult to recuperate building elements, as buildings are not designed and built in a way that allows for deconstruction rather than demolition, which renders it rather costly. Lack of knowledge of available parts within building and lack of certainty regarding the quality of reuse elements are further challenges (Condotta & Zatta, 2021; Nordby, 2019).

Repair: Smaller repairs and maintenance in the context of buildings are quite common, such as issues related to heating, ventilation, electricity or plumbing. Larger building repairs of physical deterioration, for instance due to seismic or weather events, soil subsidence, are also possible.

Refurbish: Renovation of buildings by replacing or rebuilding certain parts has been receiving a lot of attention among policy makers. This is not only because renovation prolongs the functional lifespan of buildings, but also because it holds great potential regarding improvements in the energy efficiency of buildings in their use phase. Nonetheless, the renovation rate in the EU remains quite low, at around 1 to 2% of building stock per year (Artola et al., 2016). Common renovation measures concern the building envelope (e.g., wall insulation, roof insulation, windows) and the building service systems (e.g., heating, ventilation, water, energy) (Fawcett & Killip, 2014).

Remanufacture: In the context of construction practices, no clear distinction was found between remanufacturing building components and the reuse of these components.

Repurpose: Construction elements can also be reused for a different purpose from their original one. So far, however, this has been rather limited to singular proof-of-concept projects, which demonstrate the feasibility, the application of technology to facilitate repurposing, design considerations, and barriers that need to be overcome to scale the repurposing of construction elements. An example of these projects is the wooden dome built by the Circular Engineering for Architecture lab at ETH Zurich, which was built from repurposed wooden floor beams (Künzler, 2022).

Useful application of materials ("closing the resource flows")

The final two CE strategies presented below aim to recover as much value from materials at the end of the lifecycle of products, either in the form of recycled materials or energy recovery from waste incineration.

Recycling*:* The recycling rate and the potential for increasing it depend on the respective building material: metals such as steel, aluminum and zinc are almost always recycled if technically possible. Concrete, as one of the most GHG emission intensive materials is recycled at a much lower rate. In Switzerland, less than two third of the used concrete is available for recycling with the other 30% being landfilled. Out of this fraction, about 95% is recycled (Savi & Klingler, 2020). Much concrete recycling is open loop recycling, meaning that it is used for a different purpose after recycling. In the case of concrete, the recycled aggregate material is mainly reused for purposes such as road construction. However, due to the demand for such aggregate material not being as large as the volumes of available concrete from demolished buildings, this might lead to demolition waste not being re-absorbed into the industry (TU Delft, n.d.). Closed loop recycling, whereby the recycled product fulfils the same purpose, is common for steel. The steel plants in Switzerland, which cover about half of the steel demand for construction, use discarded steel as their main material source (von Hunnius, 2015). Low recycling rates occur for sheet glass (15%), gypsum (17%), wood (10%) (Gauch et al., 2016).

Recovering: Energy can be recovered through the incineration of waste materials. For instance, in Switzerland approximately 87% of wood waste from the construction industry is incinerated (Gauch et al., 2016).

Table 1. Overview of circular strategies in order of priority according to (Potting et al., 2017) displaying examples of circular construction practices from the view of a building.

Circular strategy		Definition	Circular construction practices
Smarter product use and manufacture	Refuse	Make product redundant by abandoning its function or by offering the same function with a radically different product	N/A
	Rethink	Make product use more intensive (e.g., through sharing products or by putting multi-functional products on the market)	(i) Adaptable design/multi-purpose buildings (e.g., neighborhood centers) (ii) Modular design (iii) Shared spaces (e.g., office spaces, study spaces) (iv) Smaller dwellings/larger household sizes
	Reduce	Increase efficiency in product manufacture and use by consuming fewer natural resources and materials	(i) Substitute with more sustainable material (e.g., concrete and steel with wood) (ii) Substitute/reduce use of hazardous materials (iii) Use renewable energy (e.g., for producing steel) (iv) Optimize design to use less material and energy per unit of production (e.g., using less steel); optimize logistics network
Extend lifespan of product and its parts	Reuse	Reuse by another consumer of discarded product which is still in good condition and fulfils its original function	(i) Keep building in use until end of lifetime (ii) Reuse discarded products in their original form (e.g., structural elements, windows, etc.)
	Repair	Repair and maintenance of the defective product to use it again with its original function	Repair defects and maintain building and building components such as the ventilation system
	Refurbish	Restore an old product and bring it up to date	Renovate old building by renewing specific parts (e.g., building envelope, heating system, water supply, ventilation, energy source)
	Remanufacture	Use parts of a discarded product in a new product with the same function	Reuse discarded products in their original form in a new building (e.g., structural elements, windows, etc.)
	Repurpose	Use discarded product or its parts in a new product with a different function	Use discarded building materials or components in a new product with a different function (e.g., floor beams used as structuring elements)
Useful application of materials	Recycle	Process materials to obtain the same or lower quality (i) Open-loop recycling: secondary material is used to manufacture something that differs from the preceding product (ii) Closed-loop recycling: secondary material is recycled back into the product	(i) Open-loop recycling (e.g., using recycled PET bottles in buildings as fillers or mixed into concrete) (ii) Closed-loop recycling (e.g., steel made from recycled steel scraps)
	Recover	Incineration of materials with energy recovery	Incineration of waste wood with energy recovery

3. Examples of innovations for a circular construction industry

The CBI Booster serves as an open innovation platform to encourage collaboration for innovations on the topic of transforming the Swiss construction sector into a circular construction industry. The Booster provides financial and methodological support to radical ideas that have the potential to support the sector's transformation efforts. The following 12 innovations touch upon different circular strategies and apply them on single or multiple application levels.

Madaster Services Switzerland

Madaster is a cloud-based platform that aggregates information on materials, components and products within a building to generate a material passport. A material passport provides data on the characteristics of materials, products or components used in a building, which helps to assess their potential and value for reuse, and information on disassembly, which would otherwise be unknown or uncertain. In this way, they allow for greater transparency, and for the showcasing of products that have circularity potential. Thereby providing a certain security that such product design will be valuable at the point of recovery, the material passport also creates incentives for a product design that allows for circularity. Furthermore, it facilitates reverse logistics, meaning the deconstruction of a building, take back and reuse of materials, products, and components. This enables the calculation of, amongst others, the Madaster Circularity Indicator which evaluates the circular performance of a building. During the course of the CBI Booster, the project team validated the existing Madaster material and product database for the Swiss market and generate a Swiss Material database with average values that represent local conditions. The Madaster digital database allows to register buildings, as well as the materials and products used in construction. This is done with the purpose of encouraging circular design, facilitating reuse of materials and providing information on the value of these buildings or materials for reuse.

Innovation summary	Circular strategy	Level of application
Digital platform that aggregates information about products, components and materials, which is crucial to preserve and know their value for reuse.	Reuse, (refurbish), remanufacture, repurpose, recycle	

Circularity in building technology engineering

HHM has developed a prototype of a model for designing circular building technology systems with a focus on reducing embodied energy. The model included the following considerations:

1. **Refuse** - which building technology components can be omitted?
2. **Reduce** - which components can be simplified?
3. **Reuse** - which components can be taken over from a deconstruction?
4. **Recycle** - which components are made from secondary raw materials or are available with Cradle2Cradle certification?
5. **Rot** - which components are made of nature-based materials?

Through the CBI Booster, the team aims to test and compare this model to an ongoing conventional building technology project for a residential building. The aim is to understand how its application affects the building, the planning process as well as the life cycle costs and the life cycle assessment. By the end of the project, HHM should be able to use the gathered results and knowledge for real pilot projects.

Innovation summary	Circular strategy	Level of application
Including circularity considerations in building technology systems.	Reduce, reuse, remanufacture, repurpose, recycle	

Material data in greenBIM

greenBIM is a digital solution for embodied and operational energy analysis and optimization in buildings. Building information modelling (BIM) is a software system used to document the location of and connection between products and materials. BIM does not only include the building phase but can be used throughout the life cycle of a building, including use phase, deconstruction and reuse, which is why it is a valuable tool for more circularity in the building industry. greenBIM implements sustainability-related calculations in BIM while providing decision-making metrics throughout the design process and enabling architects and planners to consider environmental aspects directly in their working environment. Benchmarks on element and building level enable time saving, reliability and visualization. To date, greenBIM considers predefined building components and simplified building geometry for an evaluation in an initial building lifecycle stage. Through the CBI Booster, the team aims to further develop the tool and provide detailed material-based information. In that way, architects and planners are facilitated to design their own building components, while taking into account environmental aspects and more complex building projects and moving further in the building's lifecycle.

Innovation summary	Circular strategy	Level of application
Development of software plugin that enables architects and planners to consider environmental aspects while planning.	Reduce	

Circular flooring system

Existing flooring solutions have not been designed to be reused and readapted for different needs and functions resulting in tons of materials wasted, high maintenance costs and unnecessary resource consumption. AETERNUM aims to develop and prototype a flooring system that is modular and can be easily disassembled and reassembled. It is thus adaptable for different types of buildings, can integrate different types of mechanical, electrical and plumbing installations and be reused over multiple lifecycles allowing finishing layers to be replaced. The flooring system is manufactured using bio-based and carbon-storing material or out of recycled waste. The flooring modules have standardized dimensions, allowing them to be off-site, mass-produced.

During the CBI Booster, the first iteration of prototypes was completed, they were redesigned and now the next batch is being manufactured to be tested.

Innovation summary	Circular strategy	Level of application
Development of a modular flooring system that can be adapted and reused.	Reduce, reuse, refurbish, remanufacture	

Impact Printing

The use of excavated material as a building material is a circular and carbon neutral solution that is gaining interest in Europe. However, there are currently many challenges that stand in the way of making labour-intensive and costly rammed earth scalable in the construction industry. To address this, Impact Printing is developing an efficient robotic on-site construction process that uses a customized material consisting of local excavated material with low levels of mineral admixtures. The development of a digital design and construction strategy for the realization of this construction method should lead to a high degree of automation and reduce the CO_2 content to less than 12 kg CO_2 per m^2, which would mean a reduction of more than 50% compared to low-carbon concrete walls. Furthermore, much excavated material would otherwise end up as waste and constitutes a large proportion of CDW, using it as a building material therefore also reduces waste. The work with the CBI Booster is intended to strengthen the cooperation with industry and the business case.

Innovation summary	Circular strategy	Level of application
Development of robotic fabrication technology that facilitate the use of excavated materials.	Reduce, recycling	

IsoCott

Thermal insulation in the construction industry mainly consists of blow-in insulation materials made from recycled paper. Luuup with IsoCott offers an alternative solution for building insulation with their blow-in insulation material made from recycled textiles. In doing so, they are addressing the increasing decline of wastepaper as a resource and addressing the nearly 90% of textile waste that has previously only been incinerated or landfilled. Using otherwise discarded cotton for insulation requires no water and reduces the need for primary raw materials. Since the production takes place entirely in Switzerland, delivery routes and CO_2 emissions are reduced. With the CBI Booster, IsoCott can address the scaling of the production process and conduct a lifecycle assessment.

Innovation summary	Circular strategy	Level of application
Using open-loop recycled textiles as insulation material, replacing paper-based insulation materials.	Recycle	

Robotic fabrication of rammed earth elements

The use of rammed earth as a sustainable and circular building material has been proven for thousands of years. The robotic processing of rammed earth now available enables the scaling and local production of prefabricated rammed earth elements. This is the basis for re-establishing rammed earth in today's construction industry. To achieve this, a pilot project for a multi-story hybrid building was used to develop and test the digital and robotic production processes. In the production of the rammed earth elements, the excavated building material is poured into a formwork layer by layer without any additives and highly compacted by a robot. The construction and deconstruction of a rammed earth wall is thus completely circular. These prefabricated rammed earth elements are used as load-bearing and non-load-bearing interior wall elements. With the innovative manufacturing process "Robotic Fabrication of Rammed Earth Elements", the traditional rammed earth was reintegrated into the construction industry in a scalable way and made BIM-compatible. With the help of the CBI Booster, we aim to increase awareness of this material for sustainable construction and find projects for implementation.

Innovation summary	Circular strategy	Level of application
Development of a robotic processing of rammed earth elements, allowing for local and upscaled production.	Reduce, recycle	

Circular Construction Plastics

More than one million tons of plastics are consumed in Switzerland every year. 22% of this is used in the construction industry. Circoplast (Circular Construction Plastics) is tackling the problem of plastic consumption on construction sites and wants to create recyclable systems for the various plastic types and usages in the long term. To do this, Circoplast is identifying quantities as well as product variations, and evaluating circular economy strategies to reduce, reuse and recycle plastic in the construction industry. Circoplast is a collaboration of various partners from the industry under the leadership of REDILO GmbH. The goal is to reduce the amount of primary plastic produced, thereby reducing the environmental impact of production. With optimized management, fewer construction plastics would be burned, reducing the environmental impact of incineration. By means of the CBI Booster, Circoplast wants to use the industry network to achieve its ambitious goal and reach relevant people for future exchange on the topic.

Innovation summary	Circular strategy	Level of application
Assessing potential for more circular use of plastic in the construction industry.	Reduce, reuse, remanufacture, repurpose, recycle	

Circular, low-carbon and price competitive floor slaps

Floor slabs account for up to 65% of a building structure, are mostly made of reinforced concrete, and therefore have a major negative impact on a building's carbon footprint. Rematter is introducing a new type of ceiling system that is recyclable, low-carbon and, most importantly, price-competitive. Rematter brings one of the most sustainable solutions on the market with its hybrid clay-wood floor slab. The materials are 100% recyclable. In addition, wood and clay can be sourced locally – clay even directly as excavation material from construction sites. All connections are dry joined or screwed, which allows for an easy disassembly and re-use of all components. Compared to reinforced concrete slabs, hybrid clay-wood floor slabs contain 80% less sequestered carbon. Rematter hopes to bring about a significant paradigm shift towards a CO_2-neutral and circular society, saving over 2 million t CO_2-eq per year in

Switzerland alone. The CBI Booster will support the project in finding suitable implementation and application partners.

Innovation summary	Circular strategy	Level of application
Manufacturing technology and material innovation allowing for a more sustainable production of floor slabs.	Reduce, recycle	

Swiss Circular Construction Digital Ecosystem

In recent years, there have been several initiatives in Switzerland to promote the reuse of materials and components in the construction industry. However, the construction sector is very fragmented, and the individual actors interact little with each other. There is no overarching collaboration, which makes the process of reuse and circular construction complex and costly. Therefore, “The Swiss Circular Construction Digital Ecosystem” creates a service that enables collaboration between multiple parties such as material suppliers, transporters, demolition experts, third-party application providers and customers through a digital ecosystem. The goal is to efficiently connect buyers and sellers digitally to simplify material procurement and provide necessary ancillary services such as transportation management of building materials and construction supplies. A digital ecosystem for circular construction in Switzerland could accelerate the transition of the built environment to a circular economy. The CBI Booster will support interacting with potential customers as well as connecting with other actors along the value chain that can be useful for the development of the digital ecosystem.

Innovation summary	Circular strategy	Level of application
Facilitating collaboration and synergies between different actors in the realm of circular building.	Potentially all circular strategies	

Utilization passport for space as a resource

A more effective lever for decarbonization and material conservation lies in considering space as a resource. Instead of creating optimized new buildings, the existing building stock becomes an opportunity for circular development. With typological data (on areas, volumes, uses, spatial quality, flexibility) of existing buildings, their potential for conversion can be mapped and measured. This data is used to create an innovative “utilization passport” as an indicator of a building’s utilization potential. This makes it possible to match the space requirements of new uses, which are also typologized, with the “use passes” of existing buildings. In this way, TransForMatch makes the transformation potential of existing buildings visible and accessible for strategic planning. At the same time, the transparency and evaluation of the resource savings potential for further use creates incentives for a systematic extension of the utilization horizon of existing buildings. The “utilization passport” is to be queried across portfolios in order to evaluate locations and utilization clusters (from individual objects to settlement areas). This makes the tool effective and attractive to both public and private stakeholders in the real estate industry in terms of the circular economy across Switzerland. The CBI Booster will support the collaborative project in finding suitable implementation and application partners.

Innovation summary	Circular strategy	Level of application
Rendering accessible of information regarding type and availability of buildings, thereby facilitating more intensive use and reuse between different actors.	Reuse	

Wood in the loop

The increased use of biogenic resources in construction significantly increases the pressure on the wood resources in Switzerland. Waste wood from the deconstruction of buildings has so far been mainly burned, recovered for energy and only a very small part is recycled as material. This is because the wood must be classified as waste wood, as harmful substances might have been applied to it, and analyzing the wood to verify this would be costly and time intensive. Therefore, WoodCYCLE – which stands for "wood in the loop" – seeks to enable an onsite screening and sorting project of wood with the help of mobile devices. In this way, part of the waste wood could be re-integrated into the cycle by processing scrap wood and redistributing it to new construction sites. This helps to counteract the shortage of wood in the construction industry. The customers of such a project can be timber construction companies or wood processing companies. Within the framework of the research project, solution approaches are to be developed as to how waste wood can become a resource and be kept in the cycle. WoodCYCLE wants to prevent the premature release of the CO2 stored in the wood and provide valuable raw materials for the construction sector for the renovation but also for the climate-neutral construction of new buildings. Within the CBI Booster, WoodCYCLE wants to benefit from the exchange with experts.

Innovation summary	Circular strategy	Level of application
Facilitating the screening and sorting of wood to enable the recycling and reuse of waste wood.	Recycle, reuse, remanufacture, repurpose	

4. Call to action

Synthesizing the previous section indicates that many of the projects of the CBI Booster have focused on the strategies of **reduce, reuse, remanufacture, repurpose**, and **recycle**, and much fewer on **rethink, repair, refurbish** or **recover**. Energy recovery is considered to have lowest priority among CE strategies, since it preserves the least value of material (Potting et al., 2017), hence a lack of projects in this area might not constitute a problematic blind spot. The lack of projects around repair might be explained by the fact that repair is rarely included in discussions around CE in the building industry, since it might be either included in refurbish (renovation), or considered a common practice, anyway.

However, a greater effort to encourage projects with a focus on **refurbish** and **rethink** could be important. Both strategies have high potential regarding material savings and a reduction in GHG emissions. Studies comparing the GHG saving potential of different CE strategies in the building industry have found that approaches such as reduce or recycle, which address emissions at a material or component level, have an important but limited impact on GHG emissions (Cabrera Serrenho et al., 2019; Hertwich et al., 2020; Zhong et al., 2021). This is linked to three factors: first, the fact that since they address emissions at material or component level, they only ever have a partial impact, whereas strategies addressing impacts at a building level are reducing material demand on a higher scale, that is, they have a larger leverage (Zhong et al., 2021). Second, the fact that the slow replacement rate of buildings means that these strategies do not have a strong impact in the short to medium term (i.e., until 2050), since they are mainly implemented when building new buildings (Cabrera Serrenho et al., 2019; Hertwich et al., 2020). Third, the fact that a significant proportion of the GHG emissions of buildings occur during the use phase means that the most effective CE strategies also reduce use phase emissions (Cabrera Serrenho et al., 2019; Zhong et al., 2021). This trade-off between reduction of embodied emissions and use-phase emission must be considered to avoid some CE strategies actually leading to an increase of lifecycle emissions. For instance, keeping a building in use for a longer time might have a positive impact from a material perspective, but depending on the improvements in building technology with regards to energy efficiency, this might have more lifecycle impacts than building new.

In this context, **refurbish** and **rethink** are crucial CE strategies. Refurbishment allows for a building to be kept in use for a longer time, which reduces material-related emissions on a building scale (i.e., not only for individual materials), and, if done in line with ambitious energy standards, reduces the building's use phase emissions. Here, authors have highlighted that refurbishments are only effective if they drastically improve a buildings energy performance (Hertwich et al., 2019). Despite this potential, the renovation rate of buildings has remained quite low—around 1 to 2% of building stock per year in the EU, and around 1% in Switzerland (Artola et al., 2016; Swiss National Science Foundation, 2019). A report by the European Parliament finds the following key barriers to refurbishment of buildings: financial barriers (the cost of renovation, lack of access to finance, and low energy prices); technical barriers (lack and cost of technical solutions, lack of knowledge); process barriers (fragmented supply chain, responsibility lies with the homeowners); regulatory barriers (requirements not strict enough, unclear definitions), awareness barriers (lack of awareness) (Artola et al., 2016). It would be interesting for the CBI Booster to include projects that address these barriers.

Then, **rethink** has been found to be the strategy with the highest GHG saving potential in the building industry in multiple studies (Cabrera Serrenho et al., 2019; Grubler et al., 2018; Hertwich et al., 2020; Pauliuk et al., 2013; Zhong et al., 2021). By allowing for a more intensive use of the building, the strategy leads to a reduced floor area per person, thereby reducing the demand for buildings. This does not only lead to an overall reduction of the demand for all building materials, but also reduces impacts during the use phase. As mentioned above, rethink strategies include sufficiency, such as simply smaller dwellings, but also the sharing strategies, such as shared living, working, and social spaces. Interestingly, intensified use is often taking place out of other than sustainability considerations, for instance, financial considerations or space constraints, such as shared living among students or co-working spaces. However, there has been little active effort to encourage such practices outside of these contexts.

In contrast to other CE strategies and the projects that have thus far been part of the CBI Booster, rethink and refurbish strategies require much social and policy innovation in addition to technology and design innovation. While another type of innovation, this does not have to be beyond the scope of the CBI Booster and would be very valuable to actively encourage in future calls. Finally, it is crucial to mention that the greatest potential lies within the combination of multiple CE strategies. The CBI Booster should therefore strive to support a wide range of projects that take different approaches and strengthen synergies between different ideas and areas.

Bibliography

Artola, I., Rademaekers, K., Williams, R., & Yearwood, J. (2016). *Boosting building renovation: What potential and value for Europe?*

Benachio, G. L. F., Freitas, M. do C. D., & Tavares, S. F. (2020). Circular economy in the construction industry: A systematic literature review. *Journal of Cleaner Production*, *260*, 121046. https://doi.org/10.1016/j.jclepro.2020.121046

Bock, T. (2015). The future of construction automation: Technological disruption and the upcoming ubiquity of robotics. *Automation in Construction*, *59*, 113–121. https://doi.org/10.1016/j.autcon.2015.07.022

Bumanis, G., Vitola, L., Pundiene, I., Sinka, M., & Bajare, D. (2020). Gypsum, Geopolymers, and Starch—Alternative Binders for Bio-Based Building Materials: A Review and Life-Cycle Assessment. *Sustainability*, *12*(14), Article 14. https://doi.org/10.3390/su12145666

Cabrera Serrenho, A., Drewniok, M., Dunant, C., & Allwood, J. M. (2019). Testing the greenhouse gas emissions reduction potential of alternative strategies for the english housing stock. *Resources, Conservation and Recycling*, *144*, 267–275. https://doi.org/10.1016/j.resconrec.2019.02.001

Choudhary, J., Kumar, B., & Gupta, A. (2020). Utilization of solid waste materials as alternative fillers in asphalt mixes: A review. *Construction and Building Materials*, *234*, 117271. https://doi.org/10.1016/j.conbuildmat.2019.117271

Condotta, M., & Zatta, E. (2021). Reuse of building elements in the architectural practice and the European regulatory context: Inconsistencies and possible improvements. *Journal of Cleaner Production*, *318*, 128413. https://doi.org/10.1016/j.jclepro.2021.128413

Crini, G., Lichtfouse, E., Chanet, G., & Morin-Crini, N. (2020). Applications of hemp in textiles, paper industry, insulation and building materials, horticulture, animal nutrition, food and beverages, nutraceuticals, cosmetics and hygiene, medicine, agrochemistry, energy production and environment: A review. *Environmental Chemistry Letters*, *18*(5), 1451–1476. https://doi.org/10.1007/s10311-020-01029-2

Debacker, W., & Manshoven, S. (2016). D1 Synthesis of the state-of-the-art. *Key Barriers and Opportunities for Material Passports and Reversible Design in the Current System (H2020 BAMB Project)*.

Fawcett, T., & Killip, G. (2014). Anatomy of low carbon retrofits: Evidence from owner-occupied Superhomes. *Building Research and Information*, *42*. https://doi.org/10.1080/09613218.2014.893162

FOEN. (n.d.). *Abfall und Rohstoffe: Das Wichtigste in Kürze*. Retrieved 8 March 2022, from https://www.bafu.admin.ch/bafu/de/home/themen/thema-abfall/abfall--das-wichtigste-in-kuerze.html

Gauch, M., Matasci, C., Hincapié, I., Hörler, R., & Böni, H. (2016). *Projekt MatCH: Material- und Energieressourcen sowie Umweltauswirkungen der baulichen Infrastruktur der Schweiz*. Bundesamt für Umwelt BAFU.

Grubler, A., Wilson, C., Bento, N., Boza-Kiss, B., Krey, V., McCollum, D. L., Rao, N. D., Riahi, K., Rogelj, J., De Stercke, S., Cullen, J., Frank, S., Fricko, O., Guo, F., Gidden, M., Havlík, P., Huppmann, D., Kiesewetter, G., Rafaj, P., … Valin, H. (2018). A low energy demand scenario for meeting the 1.5 °C target and sustainable development goals without negative emission technologies. *Nature Energy*, *3*(6), Article 6. https://doi.org/10.1038/s41560-018-0172-6

Heeren, N., & Hellweg, S. (2018). Tracking Construction Material over Space and Time: Prospective and Geo-referenced Modeling of Building Stocks and Construction Material Flows. *Journal of Industrial Ecology*, *23*(1), 253–267. https://doi.org/10.1111/jiec.12739

Heeren, N., Mutel, C. L., Steubing, B., Ostermeyer, Y., Wallbaum, H., & Hellweg, S. (2015). Environmental Impact of Buildings—What Matters? *Environmental Science & Technology*, *49*(16), 9832–9841. https://doi.org/10.1021/acs.est.5b01735

Hertwich, E. G., Ali, S., Ciacci, L., Fishman, T., Heeren, N., Masanet, E., Asghari, F. N., Olivetti, E., Pauliuk, S., Tu, Q., & Wolfram, P. (2019). Material efficiency strategies to reducing greenhouse gas emissions associated with buildings, vehicles, and electronics—A review. *Environmental Research Letters*, *14*(4), 043004. https://doi.org/10.1088/1748-9326/ab0fe3

Hertwich, E. G., Lifset, R., Pauliuk, S., Heeren, N., Ali, S., Tu, Q., Ardente, F., Berrill, P., Fishman, T., Kanaoka, K., Kulczycka, J., Makov, T., Masanet, E., & Wolfram, P. (2020). *Resource Efficiency and Climate Change: Material Efficiency Strategies for a Low-Carbon Future*. International Resource Panel (IRP). https://doi.org/10.5281/ZENODO.3542680

Huang, B., Gao, X., Xu, X., Song, J., Geng, Y., Sarkis, J., Fishman, T., Kua, H., & Nakatani, J. (2020). A Life Cycle Thinking Framework to Mitigate the Environmental Impact of Building Materials. *One Earth*, *3*. https://doi.org/10.1016/j.oneear.2020.10.010

Kivimaa, P., & Martiskainen, M. (2018). Innovation, low energy buildings and intermediaries in Europe: Systematic case study review. *Energy Efficiency*, *11*(1), 31–51. https://doi.org/10.1007/s12053-017-9547-y

Künzler, R. (2022, April 26). A wooden dome made solely from waste. *ETH News*. https://ethz.ch/en/news-and-events/eth-news/news/2022/04/globe-a-wooden-dome-made-solely-from-waste.html

Li, J., Greenwood, D., & Kassem, M. (2019). Blockchain in the built environment and construction industry: A systematic review, conceptual models and practical use cases. *Automation in Construction*, *102*, 288–307. https://doi.org/10.1016/j.autcon.2019.02.005

Mahpour, A. (2018). Prioritizing barriers to adopt circular economy in construction and demolition waste management. *Resources, Conservation and Recycling*, *134*, 216–227. https://doi.org/10.1016/j.resconrec.2018.01.026

Marchuk, J. (2020). *Circular Economy in Construction Sector: Barriers for Scaling Up Construction Materials Reuse in Trondheim Region, Norway* [Norwegian University of Science and Technology]. https://ntnuopen.ntnu.no/ntnu-xmlui/handle/11250/2777020

Milford, R. L., Pauliuk, S., Allwood, J. M., & Müller, D. B. (2013). The Roles of Energy and Material Efficiency in Meeting Steel Industry CO2 Targets. *Environmental Science & Technology*, *47*(7), 3455–3462. https://doi.org/10.1021/es3031424

Moynihan, M. C., & Allwood, J. M. (2014). Utilization of structural steel in buildings. *Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences*, *470*(2168), 20140170. https://doi.org/10.1098/rspa.2014.0170

Nordby, A. S. (2019). Barriers and opportunities to reuse of building materials in the Norwegian construction sector. *IOP Conference Series: Earth and Environmental Science*, *225*, 012061. https://doi.org/10.1088/1755-1315/225/1/012061

Pauliuk, S., Sjöstrand, K., & Müller, D. B. (2013). Transforming the Norwegian Dwelling Stock to Reach the 2 Degrees Celsius Climate Target. *Journal of Industrial Ecology*, *17*(4), 542–554. https://doi.org/10.1111/j.1530-9290.2012.00571.x

Pranav, S., Aggarwal, S., Yang, E.-H., Kumar Sarkar, A., Pratap Singh, A., & Lahoti, M. (2020). Alternative materials for wearing course of concrete pavements: A critical review. *Construction and Building Materials*, *236*, 117609. https://doi.org/10.1016/j.conbuildmat.2019.117609

PwC. (2020). *Schweizer Baubranche—Differenzieren oder verlieren: Schweizer Bauakteure sprechen über Markt, Digitalisierung und ihre Zukunftsperspektiven vor und seit Covid-19*. https://www.pwc.ch/de/publications/2021/pwc-schweizer-baubranche-differenzieren-oder-verlieren.pdf

Regona, M., Yigitcanlar, T., Xia, B., & Li, R. Y. M. (2022). Opportunities and adoption challenges of AI in the construction industry: A PRISMA review. *Journal of Open Innovation: Technology, Market, and Complexity*, *8*(1), 45.

Robinson, G., Leonard, J., & Whittington, T. (2021). *Future of Construction: A Global Forecast for Construction to 2030* (p. 62). Oxford Economics. https://www.oxfordeconomics.com/recent-releases/Future-of-Construction

Sandin, G., Peters, G. M., & Svanström, M. (2014). Life cycle assessment of construction materials: The influence of assumptions in end-of-life modelling. *The International Journal of Life Cycle Assessment*, *19*(4), 723–731. https://doi.org/10.1007/s11367-013-0686-x

Schweizerischer Baumeisterverband SBV. (2021). *Studie über das verbaute Material in der Schweiz*. https://www.fskb.ch/wp-content/uploads/2021/05/SBV_Studie_Materialvolumen_2021_210x297mm_DE-web.pdf

Selman, A. D., & Gade, A. N. (2020). *Barriers of incorporation circular economy in building design in a Danish context*. 665–674. http://www.arcom.ac.uk/-docs/archive/2020-Indexed-Papers.pdf

Singh, N. B., & Middendorf, B. (2020). Geopolymers as an alternative to Portland cement: An overview. *Construction and Building Materials*, *237*, 117455. https://doi.org/10.1016/j.conbuildmat.2019.117455

Swiss National Science Foundation. (2019, October 17). *Building renovation needs to be speeded up*. Swiss National Science Foundation (SNSF). https://www.snf.ch/en/tEth3WmKg9wE4DzA/news/undefined/en/tEth3WmKg9wE4DzA/news/

TU Delft. (n.d.). *Concrete Recycling*. Retrieved 4 March 2022, from https://www.tudelft.nl/citg/over-faculteit/afdelingen/engineering-structures/sections-labs/resources-recycling/research-innovation/recycling-technologies/concrete-recycling

United Nations Environmental Programme. (2021). *2021 Global Status Report for Buildings and Construction: Towards a Zero-emissions, efficient and resilient buildings and construction sector.* https://www.unep.org/resources/report/2021-global-status-report-buildings-and-construction

von Hunnius, Y. (2015, August 11). *„Wir sind der grösste Recycling-Betrieb der Schweiz“*. Dialogportal Grüne Wirtschaft. https://www.gruenewirtschaft.admin.ch/grwi/de/home/Gruene_Wirtschaft_konkret/Wir_sind_der_groesste_Recycling-Betrieb_der_Schweiz.html

Wollny, B., & Bundesamt für Statistik BFS. (2022). *Schweiz—Unternehmen Baugewerbe nach Größenklassen*. Statista. https://de.statista.com/statistik/daten/studie/786769/umfrage/unternehmen-im-baugewerbe-in-der-schweiz-nach-groessenklassen/

Zhong, X., Hu, M., Deetman, S., Steubing, B., Lin, H. X., Hernandez, G. A., Harpprecht, C., Zhang, C., Tukker, A., & Behrens, P. (2021). Global greenhouse gas emissions from residential and commercial building materials and mitigation strategies to 2060. *Nature Communications*, *12*(1), 6126. https://doi.org/10.1038/s41467-021-26212-z