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RECREATING THE CONSTRUCTION SECTOR FOR CIRCULARITY

Catalysing the reuse of prefabricated concrete elements

Satu Huuhka, Leena Aarikka-Stenroos, Jukka Lahdensivu, Paul Jonker-Hoffrén, Viktoria Arnold, Erik Stenberg, Rijk Blok, Kjartan Gudmundsson, Patrick Teuffel, and Angelika Mettke

Introduction

This conceptual chapter discusses how the construction industry can transform itself into a circular and low-carbon sector. The construction sector is presently one of the largest waste-generating industries (O'Grady et al., 2021; Pomponi & Moncaster, 2017; Solis-Guzman et al., 2009) and producer of CO_2 emissions (Chen et al., 2022), and one of the largest consumers of raw materials and energy (UNEP, 2019). Even though it has been noted that the construction sector has a high potential for the use of circular economy (CE) principles and to create value by exploiting them (Smol et al., 2015), it is still at an early stage in the transition to CE (Hossain & Ng, 2018). The sector's impacts are not limited simply to construction activities but include upstream industries (raw material extraction and construction material manufacture) as well as downstream industries (the real estate and housing sectors). Therefore, transitioning the construction sector towards climate neutrality and circularity is focal for any society striving to transform its trade and industry so that the inflicted burdens do not exceed the planetary bearing capacity.

Moreover, this chapter investigates how circularity on a high level, that is to say the reuse principle, can be catalysed in the sector. In CE, solutions are favoured that preserve already extracted material resources in use, thus avoiding further extraction and waste generation. This can take place either through continued use or through the reuse or recycling of obsolete products. In Europe, the European Union (EU) has authorised a waste hierarchy stipulating that continued use should be prioritised over reuse, and reuse over recycling (European Union, 2008). Reuse is considered to create more value, since existing products and components are retained and put into new use via factory-refurbishment, remanufacturing, or redistribution; whereas in recycling, the product/component is reprocessed into a secondary material (den Hollander et al., 2017; Bocken et al., 2016; Lüdeke-Freund et al., 2019). However, in the construction sector, only a marginal proportion of construction and demolition waste (CDW) materials is presently directed at reuse as

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construction products in their original function (e.g., reusing a window as a window). Recycling remains the sector's business-as-usual modus operandi, and often results in downcycling, meaning that the recycled material will not be applied in structures and purposes equally demanding to those that the secondary material came from.

This chapter specifically examines the reuse of precast concrete elements. Most construction is made out of concrete globally, and consequently, concrete also dominates emissions of building materials and CDW generation. Concrete structures can be either cast in situ or precast in a factory and assembled on the site. As opposed to in situ casting, the prefabrication of elements results in components more favourable to reuse, even if most precast elements have not been specifically designed for disassembly. In Europe as well as in many other contexts, precasting in factories has been employed since the 1940s (Alonso & Palmarola, 2019). Consequently, countries have accumulated significant building stocks with panels and other prefabricated elements with the unlocked potential for reuse.

The purpose of this chapter is to present how, in the construction sector, the CE transition can take place by the increased adoption of the reuse principle, particularly the reuse of concrete elements in new buildings (Figure 3.1). Methodologically, this chapter is a conceptual one. Its insights are theoretical and originate from the planning of the Horizon 2020 project ReCreate, short for 'Reusing prefabricated concrete for a circular economy', which runs from 2021 to 2025. The aim of the project is to facilitate the deployment of the deconstruction and reuse of concrete elements as technologically and economically viable industrial processes. The focus is on elements that have not originally been designed for deconstruction. Therefore, this chapter discusses how the learnings acquired in planning and executing the ReCreate pilot projects in four European

Figure 3.1 Concrete elements deconstructed from the buildings behind them (left). Location: Finland. A new building made from deconstructed elements (right). Location: Germany. Photos: SH.

countries – work in progress at the time of writing – can help the construction sector to transition from a linear to a circular economy beyond the pilots themselves as well as beyond the borders of the project countries. The project and its approach are multi-, inter-, and transdisciplinary, covering not only construction and the related disciplines of architecture and civil engineering, but also the domains of demolition, materials science, environmental impact assessment, economics, the sociology of work, and regulation and public policy. This approach also allows the display and discussion of diverse technological, economical, and societal aspects that can catalyse the transition to a more circular modus operandi in the construction sector. Consequently, this chapter draws from various disciplinary vocabularies pertaining to the diverse disciplinary fields while still being positioned primarily within the construction sector research.

This chapter considers CE catalysts as factors enabling the implementation of the reuse to advance circularity and CE principles in the construction sector. The definition follows that of Cabell and Valsiner (2011), proposing that catalysts are positive ‘helpers’ that initiate and facilitate change processes. Focal catalysts encompass feasible deconstruction technologies and work processes, robust protocols for verifying the deconstructed elements’ properties and quality, remanufacturing processes turning the elements into ready-for-reuse construction products, and regulation that acknowledges their recertification. It is also noted that key persons in stakeholder organisations, willing and positioned to ease this transition, can be considered catalysts in their own right. Moreover, it is considered that an extractable urban mine of a sufficient volume and a functional circular value chain, consisting of separate but connected operators, are also crucial for realising the upscaling potential of reuse. In brief, a wide variety of interlinked catalysts are required to operate simultaneously to facilitate a transition to circularity.

Background

Catalysing a technological transition

The ReCreate approach is inspired by Frank Geels’s (2002) theory on technological transitions, which builds upon technology studies and evolutionary economics. Geels conceptualises technological transitions within the context of a multi-level perspective, consisting of a nested hierarchy of a socio-technical landscape, socio-technical regimes, and technological niches. Here, the landscape means a slowly changing context formed by a multitude of wider factors external to technology, such as (geo-)political, cultural, environmental, and economic structures and values. Regimes stand for the integrated configurations of routines, practices, and rules of individuals and organisations, pertaining to both engineers and other involved social groups, such as financers, regulators, and users of products, etc. The intertwined web of actors, products, and rules in these regimes create a kind of stability that constrains innovation on path-dependent trajectories, making any innovation incremental at best. Niches, on the other hand, are environments sufficiently protected from normal market mechanisms that can give birth to radically different innovations, which characteristically are expensive, low-performing, and unwieldy at first. They provide room for learning and building necessary social networks to support the innovations, such as value chains (Geels, 2002).

Niches are embedded in regimes and regimes in landscapes, meaning that novel technologies are developed in the context of the knowledge and capabilities arising from the existing framework. Often niches emerge from landscape developments to address problems within prevailing regimes. Geels suggests how radical innovation can break out of a niche into an existing regime via gradual niche cumulation, that is, by conquering one market or domain after another. For a breakthrough to successfully happen though, simultaneous developments in the regime and landscape are needed that reinforce the process. The landscape level, for one, may transform in a way that also pressures a regime to change. Tensions, such as differences of opinion, within a regime may weaken the regime's stability. In this way, windows of opportunity can open for new technologies to establish themselves within a regime. Mechanisms for this include technological add-on or hybridisation, where new technologies pair up with old technologies to form a symbiosis rather than present a direct challenge. Alternatively, new technologies can ride along the growth of specific markets in which the new technology is for contextual reasons a better solution than the existing one. Eventually, such changes can cascade and over time lead to an old regime reconfiguring into a new one in all of its dimensions (technologies, value chains, policies, markets, users, etc.) (Geels, 2002).

Catalysing circularity and the move from recycling to reuse in the construction sector

How then has the construction sector so far shifted towards more circular operations? The sector is very material intensive (Zimmann et al., 2016), so substantial material streams are both produced and consumed, and it also results in several side streams and waste generation. Therefore, the CE and more circular, resource-efficient operations implementing CE principles have been suggested for solving many of the sector's environmental problems (Hossain & Ng, 2018; Pomponi & Moncaster, 2017; Reike et al., 2018). However, the CE implementation in the construction sector is following the same biased patterns seen in society. Out of the hierarchical principles of CE – the so-called R imperatives 'Reduce, Reuse, Recycle' – the lowest-level option, recycling, dominates (see also Ghisellini et al., 2016; Ranta et al., 2018). It is often most easily applicable to the operators' own activities. This can also be seen to support Geels's (2002) argument about path dependency.

By harnessing the reuse principle in the construction sector and by reusing building components, it would be possible to achieve major environmental benefits (Zabek et al., 2017), such as lower CO_2 emissions (Çimen, 2021), but also create economic value (Hopkinson et al., 2019; Stahel, 2016). However, component reuse is a radical niche innovation, and as such it faces resistance from the construction sector regime. Component reuse triggers diverse technical, business, and societal challenges, such as rising costs, low market demand, and the need to develop reuse technologies (Densley Tingley et al., 2017; Hopkinson et al., 2019).

The literature has suggested diverse catalysing factors that could advance the implementation and adoption of the reuse approach in the construction sector. These factors range from the technical to the more societal: Densley Tingley et al. (2017) propose that digital solutions could be used to store and retrieve information from surrounding suppliers and reusable materials; market demand should be initiated, and training and guidance on material reuse should be provided as well as governmental influence could provide support. Also, many technological aspects, such as dismantling methods (Hopkinson et al., 2019) and tools for reusability analysis for different parts of the building (Akanbi et al. 2018), need further development to facilitate reuse in the construction processes. Solutions are also needed for transportation of the secondary products and materials (Gallego-Schmid et al., 2020). In addition to technical and economic factors, societal factors are crucial in advancing reuse in the construction sector, because stakeholders' perceptions of the risks of material reuse shape the reuse of building components (Rakhshan et al., 2020). It appears that currently, the implementation of reuse projects has depended on the vision of a few individuals in key positions in their organisations (Huuhka et al., 2019).

The ReCreate concept

Geels (2002) documented how technological transitions may occur with the use of a historical case study of the transition from sail ships to steam ships. His theory on technological transitions is used to explain how the ReCreate project approached catalysing future technological transitions. The ReCreate concept (Figure 3.2) is based on a multi-, inter-, and transdisciplinary approach focused on the collective problem-solving around real-life pilots, both for deconstruction and for reuse of deconstructed components. The 2021–2025 project takes place in four EU countries – Finland, Sweden, the Netherlands, and Germany – where at least some prior experience of precast concrete component reuse exists, and the project covers different building and element types, including residential, commercial, and industrial buildings and from panels and slabs to columns and beams. The pilots are deployed as a focal means to research and develop deconstruction and reuse in an operational environment to identify and work with key issues and to provide solutions, such as catalysts.

The approach is premised on the idea that the acts and business of construction are at their core human activities, even though technology is the foundation for human actions. Reuse in construction requires viable technologies enabling deconstruction, quality inspection and assurance, remanufacturing/factory refurbishment, efficient logistics, and redesign and reassembly. Nevertheless, we believe that for a wider deployment of reuse, it is important to tackle aspects pertaining to work, regulation, and business processes, such as acquiring new skills, having regulation that recognises and justifies (and even supports) reuse, and understanding the business determinants, and this will be even more important in the long run. In Geels's (2002) terms, the

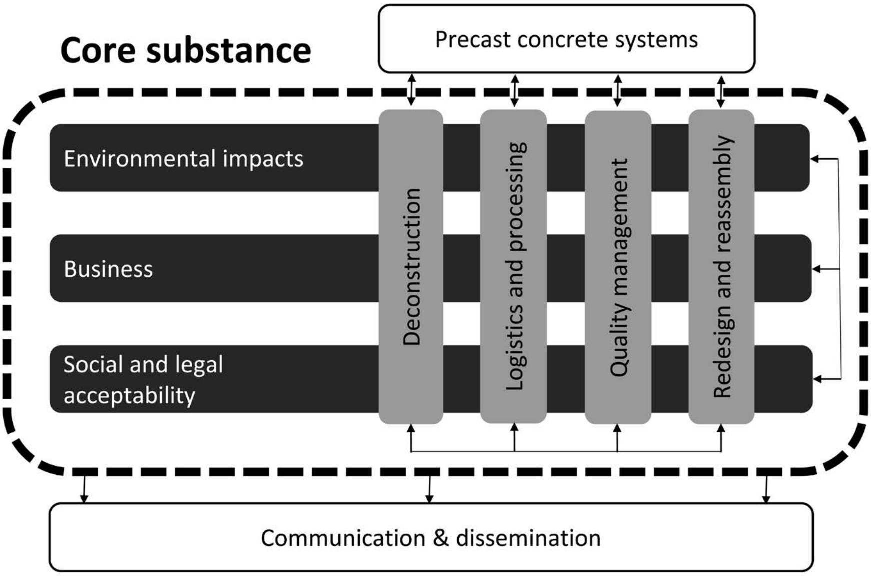

Figure 3.2 ReCreate's view on disciplinary expertise and the competences needed to transition the construction sector towards reuse. Socioeconomic perspectives (black horizontal) cross-cut technical perspectives (grey vertical). Existing knowledge on precast systems (white, top) feeds the research, but also draws from it when it comes to evaluating the business potential at large. The core substance – studied with the help of real-life pilot projects – is drawn also from for knowledge sharing (white, bottom).

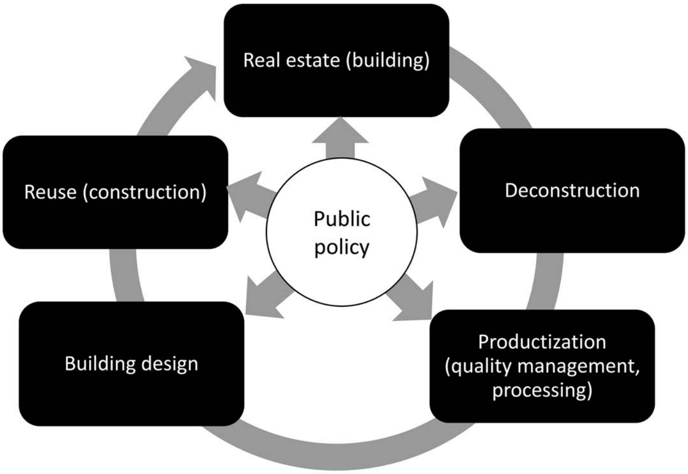

Figure 3.3 The circular value chain of reuse from (donor) building to (new) building.

former can be understood as developments within the niche, while the latter denote construction sector regime changes.

Thus, the next two sections of this chapter will cover both of these aspects. First, the section 'Catalysing the pilot projects' reflects how these pilots can be materialised and what kind of technological, process operational, and other considerations may come into play in the required technical activities of deconstruction planning, deconstruction, quality inspection, factory refurbishment, information management, building design, and reuse in a new building. Second, the section 'Catalysing wider adoption' discusses more societal factors focal for the upscaling of the novel reuse-enabling technical processes developed in the pilots in the wider construction industry. These factors include numerous socioeconomic factors, such as 1) learning novel work processes and skills throughout and at all levels of the value chain (Figure 3.3), 2) the acknowledgment of reuse in regulation, standards, and tendering, 3) business potentials and value creation and capture mechanisms in deconstruction and reuse, and 4) surveying the potential for reuse in building stocks. The next section discusses the role of landscape developments and their pressures on the construction sector regime in creating a window of opportunity for the reuse niche and the ReCreate project to emerge in the first place. In the concluding chapter, these factors are discussed as catalysts of different types and reflected on in more detail against Geels's (2002) theory of technological transitions.

Landscape developments and regime changes that catalysed ReCreate

The groundings for implementing the reuse principle in modern construction have long existed. The niche of deconstruction and the reuse of concrete elements has existed since at least the early 1980s, when the concept emerged nearly simultaneously in Sweden and the Netherlands (Huuhka et al., 2019). Deconstruction and reuse have been studied in Germany since the early 1990s, through the 'Stadtumbau Ost' urban renewal programme. The 2000s were a particularly active decade with several implemented deconstruction and reuse pilot projects. This created some sort of potential for a niche breakthrough in the German market, which did not occur. Activities in

Germany largely wound down by the late 2000s, but research in Finland kicked off at around the same time. In Finland, the first – and so far the only – Finnish pilot was constructed by 2010. As in Germany, its construction was connected to a mass housing renewal programme, but the focus was not yet on sustainable construction or CE.

The 2010s were not particularly active in terms of building deconstruction and reuse research, but towards the end of the decade, a substantial change in the socio-technical landscape became noticeable. In the EU, climate change and other impending global environmental crises came to the awareness of policymakers and the general public, giving rise to calls for low-carbon, carbon neutral, and circular industries. These calls were reflected in the European construction sector, which during the 2000s focused almost exclusively on the operational energy efficiency of new buildings. Towards the end of the 2010s, the industry became aware of the emissions 'embodied' in building products (i.e., emissions occurring in their raw material extraction and production), too (cf. Röck et al., 2020).

Presently, the pressure from the socio-technical landscape is changing the construction sector regime; new regulation, which requires lower-carbon and more circular construction is being put into place in the EU. We discuss these regulations shortly, but now point out that pioneering companies in the sector are establishing sustainability policies and programmes of their own, which reflects the linkages within the construction sector regime, even appoints towards a transition. The commitment to these sustainability policies is encouraging individuals in key company positions to become more open to change and to partner with research bodies to introduce radical innovation, such as deconstruction and reuse. With public funding, niche environments as projects can be created; these projects are protected from normal market mechanisms. It is here that the companies of the deconstruction-reuse value chain can establish relationships and obtain knowledge that is essential for scaling up from a niche. One example of such public financing is the EU innovation funding for ReCreate,

Catalysing the real-life pilots via technology (and process) development

Deconstruction planning and practical deconstruction

Donor building

The process aiming at reuse begins with identifying a so-called donor building, made from precast concrete elements and scheduled for demolition. From this donor building, elements can be deconstructed. Once a donor building is available, its analysis starts with a pre-deconstruction audit, under development in ReCreate, which differs from a conventional pre-demolition audit (European Commission, 2016) by having a specific focus on the reusable components and their extraction while still fulfilling the pre-demolition audit's requirements for waste management purposes. The pre-deconstruction audit is usable not only in identifying the potentially reusable elements of the donor building, but also in identifying the different potentials of structures and in directing them towards the highest-quality end-of-life alternatives. Elements or structures not deemed reusable can still provide high-quality mineral and other non-mineral secondary raw materials for recycling.

Pre-deconstruction audit

The pre-deconstruction audit can include an assessment of the available construction drawings and documents, a visual inspection of the building, on-site verification that the available documentation matches what was built, and a review of the connections between the elements based on the legacy drawings. An inventory of the numbers and types of distinctive elements must be made, either as a list or as an ‘inventory model’ in a Building Information Modelling (BIM) programme. When a BIM model is used, it can be populated with information gathered throughout the assessment process, as we will explain in more detail later. The audit may also want to examine how secondary fit-out materials are connected to the elements. Inspections to detect possible harmful substances and to survey the physical condition of the elements, as well as their material and structural properties, are vital parts of the pre-deconstruction audit (see the next section). In the case of missing or nonexistent construction drawings, the inventory can be complemented by digital building scanning methods, such as laser scanning or photogrammetry for the entire building, and by performing digital rebar scanning to detect the reinforcement layout of individual elements.

Deconstruction planning

Based on the inventory and an analysis of the building, structural and practical deconstruction plans will be made. The structural deconstruction plan addresses the order and sequencing of deconstruction, including (1) specific locations of cuts and drill holes to be made, (2) the type, number, and capacity of necessary lifting anchors, (3) measures needed to ensure the structural stability of the building frame, and (4) labelling the individual elements with unique identifiers to ensure full traceability of the elements once they leave the building. The practical work plan must state multiple factors: (1) the recommended and alternative methods of harvesting and handling the elements, including the equipment involved in the cutting, sawing, drilling, jacking, pulling, hoisting, and so forth, (2) the measures to ensure the health and safety of workers during each stage of the deconstruction, and (3) site logistics, such as the storage of elements on site, timing of the deconstruction and transportation, and the weather protection measures of the donor building and elements. In addition, the practical work plan must state the correct attachment of the physical tracing tags (see the section on information management), the unique identifier labels, to the elements; once the labels are attached, they must remain in place until the reuse process is completed. The execution of the deconstruction may include some on-site testing to see whether the planned deconstruction methods and handling work are as expected. If necessary, the deconstruction work plan can be revised.

Ensuring the health and safety of salvaged components

Quality management process

In new construction, there are established quality management practices for all building components and products. In the case of the reuse of deconstructed building components, the quality management process must be created. The quality management and authorisation process proposed in ReCreate consists of several steps (Figure 3.4). This process covers the whole value chain, starting from the pre-deconstruction audit (see the previous section), to condition investigation

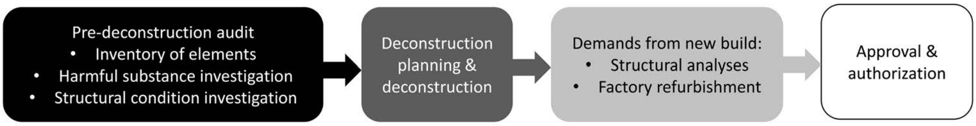

Figure 3.4 Quality control and authorisation process.

and deconstruction, to factory refurbishment/modification, testing, and reassembly (reuse). All the phases must be well-documented to ensure the quality of the reused building components.

While in use, construction materials and structures can deteriorate in several ways: they can be exposed to the outdoor climate, overloading, or harmful substances, such as asbestos. Damage to the components can also occur during deconstruction, transportation, storage, or reassembly. The possible presence and impact of deterioration and harmful substances can limit or prevent reuse and must therefore be determined before informed decisions about the deconstruction and reuse of building components can be made. This information will be acquired through a harmful substance investigation and a structural condition investigation. As much of the assessment and testing as possible should be performed before the deconstruction to avoid deconstructing components that have no residual value left. These investigations are considered an essential part of the pre-deconstruction audit.

Harmful substance survey

A harmful substance survey conducted according to standardised procedures (e.g., found in RT 18-103501, which communicates the industry best practice in Finland) will help identify the presence and amounts of polychlorinated biphenyls (PCBs), asbestos, absorbed hydrocarbons, lead traces from panel seam sealants, mould in the insulation, etc. The survey starts with tabulated information, given that the products used in the building can be identified and are well-known (e.g., certain asbestos-containing flooring and insulation products). Unknown materials and hygrothermally suboptimal structures prone to mould growth must be sampled and studied in an accredited laboratory. A risk assessment reviewing past functions of the building helps to identify potential contamination from the building's use, such as the risk of hydrocarbons leaked from machinery and absorbed into concrete during industrial use and is an aid in determining the locations and numbers of samples for laboratory testing. A similar procedure applies to mould growth–prone structures.

Structural condition investigation

A structural condition investigation, following current best practices (Lahdensivu et al., 2019), will help to identify the presence of weather or use-induced deterioration, and aids in the tracing of mechanisms behind deterioration. Typical deterioration of concrete structures includes carbonation-induced corrosion of reinforcements in structures exposed to the outdoor climate, and structural freeze-thaw damage, which can be found in cold climates. Moreover, chlorides in coastal areas and alkali-aggregate reactions may deteriorate concrete structures. The structural condition investigation will provide first, an estimation of the remaining service life of the structure under investigation in the present or planned new environment, and second, an estimate of the service life if different types of refurbishment measures are undertaken on the structure.

Factory refurbishment and legal confirmation

Material properties

In addition to damage and degradation, it is essential to uncover the essential material and structural properties of the elements to define their load-bearing capacities and other functional specifications as a part of the refurbishment process. The properties of deconstructed elements and their materials can be uncovered with the help of laboratory tests. Most of the tests are standardised (European or national standards) and can be adapted for this purpose. Construction materials are typically inhomogeneous, meaning that their properties can vary significantly. Therefore, the number of samples must be large enough to ensure that the components are safe to reuse. The planned reuse will influence which material properties of the elements should be studied. The tests will typically include the compression strength of concrete, E-modulus of concrete, E-modulus of steel bars, tensile strength of steel bars, freeze-thaw resistance of concrete, porosity of concrete, and carbonation depth of concrete.

Structural properties

Based on the material properties, the properties of the structures will be determined first by calculations and, if necessary, by testing a sample of elements on a 1:1 scale to verify the results of the calculations. The most relevant structural properties the calculations will determine are the bearing capacity of the structure, the durability properties (remaining service life) of the structure if the exposure class changes in reuse, functionality and bearing capacity of connections and lifting anchors, fire resistance of the structure, and cover depth of steel bars. In the case of virgin elements, testing standards often define how many samples should be tested. When such standards are applied to deconstructed components, the number of tested elements needs to be determined on a case-by-case basis according to statistical studies to reach a predefined safety factor (such as 95%).

Refurbishment measures

Structural elements may be damaged from overloading or become damaged during deconstruction and/or transportation. These structural damages are defects, and must be examined on a case-by-case basis as a part of the factory refurbishment process before the elements can be approved for reuse. Suitable examination techniques are strongly dependent on the type of deterioration of the elements. The simplest examination is a visual inspection of the element for cracks (width, length, and location in the structure) and based on these findings, deduction of the meaning of cracking, the need for repair, and viable repair techniques. Furthermore, there may be a need to resize the elements at the factory to the new, desired dimensions, to strip coats of paint off surfaces, or to retrofit new connecting devices if the original connecting devices have been cut during deconstruction. It may also be necessary to verify the performance of the new retrofit connections through 1:1 testing, in addition to calculations.

Legal confirmation

As the final step, the proposed factory refurbishment process encompasses a framework for legal confirmation that addresses the issue of liability. It builds upon existing construction product certification frameworks, such as the CE mark (Conformité Européenne), and associates the refurbished element with a quality class, which defines the element's suitability for different applications.

Managing information digitally in the reuse supply chain

Need for information management

As the previous sections illustrate, the deconstruction-reuse process is an information-intensive one. When compared to relatively homogenous virgin production, the required information is much more fragmented, and even element specific, since a singular element's location in a building may have influenced its current characteristics (e.g., via degradation). Thus, effective management of the information through digital workflows is essential to facilitate reuse. Ideally, BIM could be used in the future to create, store, and share structured data that various actors of the supply chain can use.

Building information modelling and digital twins

Design authoring software can be used to create templates for the digital models of the various types of building elements. The templates will define the necessary information regarding geometry, attributes, classification, and relations to other objects. The digital template can be used to create a digital instance, a digital twin, of a physical building element. This digital twin can be associated with data from the various stages of the supply chain, such as the pre-deconstruction audit, deconstruction, quality management, design processes, and factory refurbishment. The data may entail, for instance, measurement data from 3D scanning, data from material and structural testing, or environmental data related to the element's embodied CO_2. The data may also include historical information, such as building project-specific data or data from the original producer. The data will be of various formats from different software and may have to be captured with devices such as scanners, sensors, laptops, or mobile phones. Effective workflows for data exchange will require interoperability so that different actors and software can share data without the loss of information. Furthermore, it would be ideal if the data exchange would be automated as opposed to a manually uploaded and downloaded event. Workflows will also have to take into account the conversion of documents into structured and machine-readable data.

Data sharing requirements and current status

While proprietary software platforms will, in some instances, be necessary to create the digital twins of elements and the associated data, it is important that the information can be shared with a standardised data model, on vendor-neutral and open file formats, such as the Industry Foundation Class (IFC) format. Access to the data should be ensured with a common data environment (CDE) that is a central online data depository. The CDE should offer the possibility to control access to the data and authorisation to manipulate data while keeping a ledger of transactions. Construction sector CDEs can store any form of electronic data and are commonly equipped with special features for viewing 3D models and for the sharing of BIM models. In addition, a CDE for reuse must contain documentation of the donor building, including drawings, listings of relevant building codes and standards, and the documentation of design values, such as material and structural properties. As deconstruction and reuse increase as a practice, the CDE must be equipped to make the selected data available for real-time publication in existing and future digital marketplaces and material passport/urban mining portals. Today, these services often contain minimal product information on deconstructed components and lack details that are essential for reliable quality management and reuse.

Tracing

Either Radio Frequency Identification (RFID) or Quick Response (QR) is used to tag individual physical precast concrete elements and to connect each of them with their respective digital twin. The RFID or QR tag, attached to an element's fabric before a building's deconstruction, will help track the element throughout the logistic processes from deconstruction to reuse. It will also provide a link for up- and downloading data related to testing, refurbishment, and retrofitting processes into the digital model.

Designing and building with reused components

A reverse design process

The design of buildings and structures with reused elements turns the whole design process upside down. Conventionally, a design team of architects and engineers develops a building design, which fulfils the given boundary conditions for the building, site, and its use. Based on that design, all the required architectural and structural elements are made to measure. By contrast, to reuse deconstructed components, the redesign team must work with a given stock of existing building elements, which should be employed in the new building configuration. This new constraint will influence the scope of work and roles of the design team members and induce a greater need for collaboration.

Design parameters

To facilitate the reuse of existing elements in a new building design, a clearly defined framework of design parameters is necessary to support the design process. Apart from the most obvious, such as the geometry or material properties of the elements, there is a long list of more detailed essential technical information, including but not limited to the amount of steel reinforcement in the elements, the layout of the reinforcement, and potential degradation due to environmental exposure that a structural engineer will need to know. Based on these factors, as well as knowledge of the intended new use, the necessary factory refurbishment measures can be defined.

Connectors

An important aspect influencing the redesign process is the type of connections between the elements. Ideally, the existing connections between the elements can be opened and, given that their performance can be verified, used again to connect elements to one another. In reality, many connections may need to be cut or will be damaged during the deconstruction, so innovative connectors, preferably designed for disassembly (DfD), should be developed for future use and reuse.

Assigning existing elements to a new design

When a design team attempts to fit an existing stock of elements into a given new design, a perfect match is unlikely to occur. If needed, some dimensions of elements may be changed during the factory refurbishment process; for instance, hollow-core slabs may be shortened. Elements may usually not be substantially lengthened, though, and not all elements can be shortened, such as pre-tensioned elements. Thus, viable ways to compromise between the elements and the design are essential. Different design approaches will offer different possibilities, such as conventional tacit knowledge-based design, digitally optimised design using parametric modelling and BIM tools that draw element information from a digital database (CDE), and the application of artificial intelligence (AI) and neural networks in supporting the designers' decision-making process.

On the construction site

If the elements are factory-refurbished, the reuse may not differ substantially from building with virgin elements. In certain instances, larger tolerances between elements than in new production may need to be accepted. In other words, the dimensional deviations between individual elements may be greater than in virgin production, which may have a slight slowing impact on the assembly work.

Catalysing the wider adoption of reuse via societal and business development

Changing work processes need people to acquire new skills

Work as a material process

As described previously, building from salvaged elements differs inherently from producing, designing, and constructing with virgin materials; this difference is also reflected in human work and professions, as well as in work activities and methods. As the value chain is different throughout, so are the practical work activities within it; new professions may emerge, or at least the parties involved may need new or updated work skills. In sociology, the concept of 'work' can be defined as the activities that people undertake to achieve a goal; they do not just follow instructions, but the workers must use their judgement and skills to make decisions to take independent action (e.g., Wisner, 1995, as cited in Deranty, 2009, p. 70). This includes the interactions of the workers, such as the architect, engineer, or construction worker, etc., with objects, tools, machines, and technical procedures (Deranty, 2009). The translation of deconstruction and reuse from merely an idea into material work processes that are integrated and scalable is focal for the wider deployment of the ReCreate approach.

New tasks and processes for deconstruction

Deconstruction calls for new work methods because it is different from demolition and predesigned disassembly. Prior to deconstruction, a deconstruction plan must be accepted by a regulatory body that usually serves as the issuer of the demolition permit. As already described, this deconstruction plan details the phases of the process, including risks to work safety. Since deconstruction has implications for the structural integrity of the donor building, it may be necessary to provide additional calculations on the dynamic stresses that may occur during deconstruction. These can to some extent be nonstandard calculations, which may demand new or updated skills from the construction engineers as well as from the authorities evaluating the plans. When deconstruction and reuse are still at such an early phase, there may be differences in viewpoints between construction engineers and demolition experts. Since deconstruction is neither traditional destructive demolition nor pure construction in reverse, methods may need to be combined from both disciplines to successfully deconstruct a building. In principle, existing tools and skills can be deployed, but they must be reconfigured into new work processes that workers must learn. An inventory of a donor building's precast elements and an engineer's structural deconstruction plan are translated by the deconstruction firm into practical steps to retrieve the elements from the donor building, where the feasibility of the deconstruction and compliance with work safety regulations are assessed. This may also require the deployment of new tools or parts.

New workflows and data needs in building design

Similarly, redesign using salvaged prefabricated concrete elements is another part of the circular value chain that is affected. The tools used in building design are intended first, for designing building elements that will be made-to-measure, though following the manufacturers' guidelines for their characteristics, and second, for incorporating standardised, off-the-shelf building parts and materials into the design. Acquiring building elements through deconstruction can result in nonstandard dimensions and other characteristics of elements, even if the elements may be of sufficient quality and be shown to comply with regulations. Therefore, the digitalised workflows in today's building design call for accurate data of salvaged elements – such as the dimensions and results of the quality assessment of each individual element – to be available for use in the BIM tools. The circular value chain must be prepared to feed this information to custom BIM libraries of deconstructed and/or factory-refurbished elements in order to connect with the construction sector's digital planning environment. In a practical sense, this includes data for logistics as well.

Updating skills through education

Circular construction, such as the reuse of elements, may give rise to new or updated professions as construction education is reformed at all levels. These professions combine knowledge from various fields necessary to work in the circular construction industry. While new work processes in deconstruction and redesign can facilitate or improve one project at the time, education reform can have a generational effect. A further impact can be expected to take place in the labour market. In order to prevent a sharp division of workers according to circular skills or the lack thereof, practising construction workers should be encouraged to update their skills with the help of specific occupational schooling. This is crucial, as policy reports in various countries have identified shortcomings in human capital as a factor preventing the transition to CE-based construction (see Burger et al., 2019 for an analysis).

Recognising and justifying reuse in construction regulations, standards, and tendering criteria

Nexus of various regulations

The implementation of reuse in construction requires developments also in diverse regulations and standards, which shape how the construction sector can operate and what technologies, processes, etc. are considered appropriate. Deconstruction and reuse will have to operate in a regulatory nexus of work safety, waste, and construction regulations. In terms of work safety, present regulations will apply and good practices can be drawn from both demolition and construction. Waste regulation should not, as a rule, come extensively into play, since deconstructed elements are not waste but products to be refurbished and reused (Zhu et al., 2022) – though there may be regional differences in the regulations as well as their interpretation. Construction regulations are those most likely to be disrupted by reuse.

Focal construction regulations

Reusing components is in principle an act of new construction, so it must comply with construction standards and regulations that have been set, among other things, to ensure buildings are safe and healthy to use. In the EU, where ReCreate is located, some of this regulation is EU-wide, such as the Eurocodes (European Commission, n.d. a) for structural calculations and the European construction products regulation (European Commission, n.d. b), and some of it is national, regional, or even local, such as building laws and codes. In general, building codes in most places can be expected to contain some kind of special provisions that enable the development of and experimenting with new innovative solutions. While such provisions enable pilots to be constructed, it is essential that the solutions of circular construction, such as reuse, eventually become acknowledged in regulations, as perhaps different but equal (or eventually more preferable) to virgin material-based products.

Navigating construction regulations intended for virgin construction

There is no a priori reason why reclaimed materials and components could not comply with present standards and regulations. However, the fact that regulations have usually been written from a virgin material-based viewpoint may cause confusion about how reclaimed elements should be dealt with. It is fair to expect that additional testing and provision of extensive information may be required, as previously outlined, to evidence conformity with the requirements. However, in the absence of established and officially acknowledged standards and good practices for this process, individuals acting in the role of authorities may be reluctant to be among the first to clear such procedures for use. This is connected to the need to acquire new skills, as explained in the previous section, not only by the professionals in the deconstruction-reuse value chain that are producing the documentation about the elements, but also by the authorities that are tasked with evaluating whether the evidence is sufficient and convincing.

Construction products regulation

The European Construction Products Regulation (European Commission, n.d. b) pertaining to the CE mark is a good example of how the lack of acknowledgment of the existence of reused products and clear rules and processes fit with ensuring their characteristics can hinder the wider deployment of circular construction. The regulations, based on a European statute and European harmonised product standards, are intended to remove barriers of trade within the European Union. While the regulations are EU-wide and directly imposed, and as such in theory not subject to national interpretation, whether and how they apply to reuse has still been interpreted differently in different member states due to the fact that reuse has not been explicitly addressed in the statutes and standards written exclusively from a virgin production perspective. It is worthwhile noting here that construction standards and regulations are usually devised in collaboration with industry expert panels. While it makes sense to deploy the expertise of the sector in law- and policymaking, the practice can also become a hindrance to circular construction in that some of the sector's major players, which exercise primarily virgin material-based business, may be incentivised to obstruct the clarification of regulation.

Environmental assessment regulations

European standards, if not yet regulations, also exist for the evaluation of the environmental footprint of building products and whole buildings, as we will discuss in more detail in the next section. Presently, regulation is national (where it exists), so the form and requirements vary by country. The EU can nevertheless be expected to move in a direction where environmental requirements may eventually be imposed on buildings and building products at the EU level, even if only some of the member states, such as the Netherlands, have already enforced regulation at the national level. Stricter environmental requirements for building projects could be strong incentives for more circular construction, but robust evidence of reused components' environmental performance and rules of how to treat them in Life Cycle Assessment (LCA) should also be established.

Tendering criteria

In addition to regulations and standards, well-informed building owners and commissioners of buildings, both public and private, have the potential to encourage more circular practices with their tendering criteria. Quality-based tendering criteria can be devised both for demolition/ deconstruction and construction bids to reward bidders who aim at higher reuse rates as opposed to conventional low-quality recycling.

Demonstrating the environmental benefits

Environmental benefits make up one of the most substantial arguments in favour of scaling up reuse. In previous projects, it has been demonstrated that the reuse of precast concrete elements, such as floor slabs and walls, can save energy by 93–95% and reduce greenhouse gases by 95–97% (Mettke, 2010).

Requirements emerging in regulation

The quantification of a building's environmental performance has so far been practised on a voluntary basis with certification frameworks such as BREEAM, LEED, BNB, etc. However, with the new European Green Deal growth strategy, the EU aims to transform into an economy with "no net emissions of greenhouse gases in 2050" where "economic growth is decoupled from resource use" (European Commission, 2019). The Netherlands has required environmental assessment in building permits since 2013 (Staatsblad, 2011). Finland, Sweden, and Norway will soon mandate submitting a whole-life carbon assessment with a building permit application as a part of their target to achieve carbon neutrality in the building sector by 2030–2035 (Kuittinen & Häkkinen, 2020). Germany aims to achieve this goal by 2045 (Bundes-Klimaschutzgesetz, 2019) with the help of a holistic sustainability assessment with not only ecological but also economic and social aspects (Bundesministerium 2019). The Netherlands has coupled CO_2 with circularity and, like the EU, aims at carbon neutrality by 2050 (De circulaire bouweconomie, n.d.).

Environmental assessment methods

The environmental impact of products, including buildings, can be measured in a quantitative and objective fashion with the help of LCA. The EU is presently developing EU-wide user-friendly tools for assessing the environmental footprint of buildings based on the LCA, such as the Level(s) framework (Dodd et al., 2017). A full LCA consists of "a compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle" (ISO-14040, 2006). The LCA relies on Environmental Product Declarations (EPDs). To conduct an LCA for whole buildings in the design phase, a database of the EPDs of the used construction products and materials is needed.

Environmental product declarations for reused products

Currently, there are no EPDs for reused products; their environmental impact is assessed on a case-by-case basis. The development of EPDs for the main range of reused precast concrete elements, which is a task within the ReCreate project, should be a catalyst for the implementation and acceptance of the reuse of such elements. The availability of the EPDs will demonstrate the benefits of reuse to clients, architects, and other professionals involved in the LCA of buildings that are looking for ways to lower their environmental impacts – not only energy and emissions, but also the use of virgin materials, natural land (especially gravel and sand extraction), and landfill land (by avoiding construction waste). An environmental advantage quantified with the help of an LCA, through EPDs, will result in higher scores in buildings' sustainability certificates, regardless of the certification system.

Uncovering the economic value of reuse for construction businesses

Creating and capturing economic value through business model and value chain development

While regulation, as discussed previously, can soon start to encourage reuse on an environmental basis, the ReCreate approach has also encouraged diverse companies to learn how to create and capture economic value and make business from the reuse of concrete elements. These may entail, for instance, putting the company's sustainability strategies into action, developing the business model to also include reuse-based services and/or products, strengthening brand value gains, as well as serving new sustainably oriented customer segments better. As construction-sector companies are networked and form value chains, companies can also perceive the economic value arising from the sustainability shift of the whole industrial value chain, where the projects and material flows are designed to be more resource saving and efficient with less waste and emissions. To encourage companies in this direction, it is essential to uncover what the business and economic aspects are that can catalyse reuse and particularly concrete element reuse in the construction sector, and what determines the economic value creation and capture (see Hopkinson et al., 2019).

Business potential arising from innovations

The novel technological methods for deconstructing, factory refurbishing, and building out of reused elements can create novel, innovative business potential for the diverse companies that are involved in ReCreate's pilot projects, as well as for potential new entrants. The business potential that drives change in companies' businesses is grounded in different types of innovation (Aarikka-Stenroos et al., 2021). The business potential can entail technological innovations, such as software for inventory modelling or hardware for deconstruction; product innovations, such as factory-refurbished elements that can replace virgin products; and service innovations, such as pre-deconstruction audits, quality assurance and certification services, or redesign services, just to name a few examples out of the value chain demanding expertise and competencies. In other words, the reuse of concrete elements necessitates diverse companies to operate in the circular construction value chain. However, it also requires substantial development, change, and innovation from them to enable efficient, safe, and functional flows of reused elements, which then enables the emergence of economic value. This implies both new companies, with new specified products and services that are needed along the reuse-implementing construction process, but also updating existing businesses, which can modify and even renew their way of operating in general.

Cost management in the value chain

Because the construction process with reused elements is still unconventional and not 'business-as-usual', cost management throughout the value chain is crucial for business to capture value and ensure optimal cost savings from reuse and to even create profits. From deconstruction to assessment to factory-refurbishment to reuse, process innovations can shape critically whether risks and costs are realised. For example, safe work methods can diminish risks and impact costs. Several factors, such as pre-deconstruction audit methods, inventory modelling of the donor building, efficient and smart deconstruction methods, and optimised storage and logistics for elements, determine how well the reuse process can be planned and optimised in advance and to progress as planned.

Ensuring economic benefits for all companies in the value chain

To capture economic value from reuse, the economic benefits should be aligned among all key actors/companies in the value chain. This includes, for example, the owner of the donor building, the deconstruction contractor; technology and design consultants, such as structural and environmental engineers and architects; the precast concrete manufacturer; the building contractor; subcontractors; and the client. Some tasks, such as deconstruction – implemented as planned in a controlled way – can determine the quality, amount, and type of harvested elements, thereby influencing how much economic value the other actors can capture after deconstruction and create out of the harvested elements. For one, the better the physical condition of an element is, the fewer factory-refurbishment measures are needed. Also, performing an inventory of the donor building using digital building information modelling may enable the whole value chain and its actors to do their tasks in a well-planned manner, which has direct implications for the value capture potential. For example, the quality of the data on the elements deposited in the donor building influences how fluently deconstruction, logistics, factory-refurbishment, and architectural and structural design can be planned and executed.

Different pathways to create economic value from reused concrete elements

The reuse principle can be implemented in different ways to create value from concrete elements in circular construction (Riuttala, 2022). First, concrete elements may be salvaged with the intention of reusing them in demanding applications, which require high-value components equal to new components. To correspond to the quality and safety requirements dictated by the design of the receiving building, elements must be carefully selected in donor buildings and factory-refurbished to the extent that they are comparable to virgin products, tested, and certified. This allows the building contractor to gain brand value and possible tax incentives from reuse without the risk related to product quality. Another value creation pathway builds on finding secondary applications for salvaged elements, such as in less demanding buildings or in infrastructure construction (e.g., noise barriers or retaining walls). Here, the key is to find a cost-effective solution for building contractors to gain use value from existing elements without needing to resort to heavy testing and validation processes. The owner of the donor building may also retain the elements for use on the same site, or the demolition contractor can choose to resell or donate them directly for reuse. In addition, reuse can be combined with recycling to strive for the highest achievable level of upcycling and material reutilisation.

Creating and sharing precast concrete knowledge

Building stocks as urban mines of elements

For companies to capitalise on the potential of reuse across the EU, there is a need to understand how large reserves of elements could be available in the 'urban mines' of building stocks. Although the global prefabricated housing production built during the post–World War II period has been estimated to contain 170 million flats with five billion square meters of space, there is no single and reliable source that has managed to collect and map the vast amounts of prefabricated concrete used in the European post–World War II period (1945–1989) or in the more recent past (1990–2020) (Alonso & Palmarola, 2019). Similarly, there are no reliable or unified sources identifying where these buildings are located in Europe. The documentation and historical records of the prefabricated concrete construction sector from the post–World War II period has proved weak or, in some cases, simply missing. Even if one had a more precise quantitative analysis of where, when, and how the precast concrete elements were built across the European continent, the possibility to apply the deconstruction and reuse methods created in one context in another depends on the types and details of the precast systems.

Classifying precast systems and elements

To meet the aforementioned challenges, ReCreate aims to create new, detailed, and integrated knowledge of precast concrete through an analysis and classification of past and present precast construction systems and their elements. Many different sources will be consulted, such as current historical research on the subject, literature, public and private archives, industrial partners' archives and employees, and building case studies. There are also regional differences that shape the business potential for concrete reuse, and it is crucial to capture this knowledge in order to increase the reuse of elements in all of Europe. Therefore, ReCreate's aim is to establish an open database, in line with the EU's goals for open data, for precast technologies (roughly from 1945 to today) to identify, order, and create a taxonomy of relevant building, component, and connection types.

Taxonomy and database to aid decision-making

The taxonomy and database can be helpful in upscaling the reuse of prefabricated concrete in that – much like a bird-watcher's guidebook –they can help spread general and specific knowledge of reuse potential to building sector professionals and so help them make informed judgments of singular buildings they may encounter. For example, contemporary planning processes do not take reuse into consideration and often, if not always, disregard the reuse potential in the existing buildings on the site. They are seen as refuse rather than a resource. The taxonomy can be helpful for planners by raising and answering the following questions: (1) Is the specimen in question a rare instance that needs to be protected? (2) Is it rather a well-documented, common building system that already showcases a track record of successful reuse? or (3) Does it contain elements that are likely to be constructed using nonhazardous substances and robust structural capabilities? For other professionals, such as structural engineers or architects that may be commissioned to inventory a donor building's elements, the taxonomy can provide a framework for the classification of the elements and, in the database, digital twins of the elements in 3D to ease the documentation process.

Appreciation generation through knowledge creation

By sharing precast concrete knowledge across Europe, ReCreate aims to promote a more positive understanding of the existing building stock from the post–World War II period. This era is largely misunderstood; its buildings are seen as something negative, even vilified. Presently such buildings are all too often slated for demolition far before their technical life has ended. A more widespread and better knowledge of their historical origins and contemporary reuse potential could help contribute to a more sustainable and circular construction sector.

Conclusions

This chapter proposed how the circular economy transition can be catalysed in the construction industry. This chapter has focused on a high level of circularity, that is, the reuse principle, using the deconstruction and reuse of precast concrete elements as its example. Drawing from the ReCreate project, the chapter has identified a spectrum of aspects that need to be catalysed to implement an industry transformation, ranging from novel technologies and processes needed in deconstruction and remanufacturing, reuse-oriented design, information management through digitalisation, to work and skill development, regulative development, and business model and cost management development. Conceptually, the chapter used Geels's (2002) multi-level perspective of technological transitions as a theoretical framework to discuss catalysing circular construction transition. Changes in the socio-technical landscape, mainly the political drive towards a low-carbon and circular society, have opened up a window of opportunity in the present time for reuse to break out of its niche, since there is pressure for the construction regime to change. Figure 3.5 illustrates these linkages.

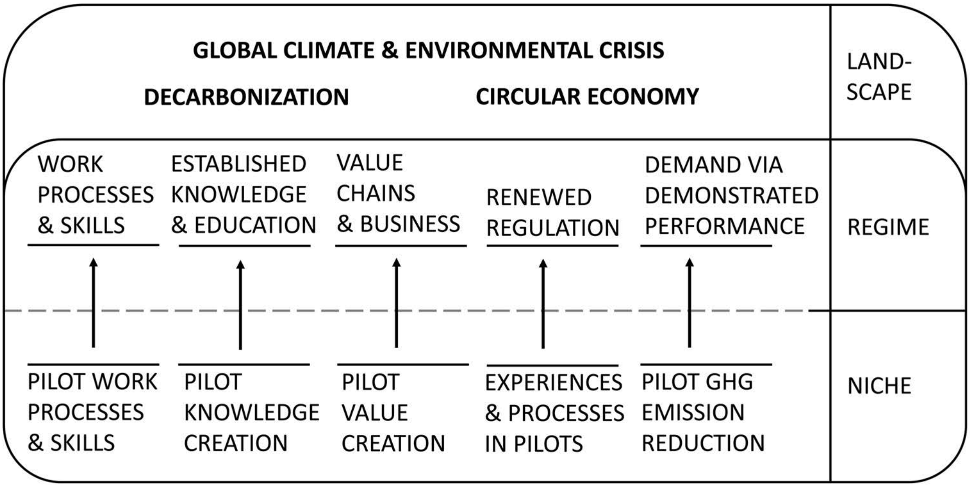

Figure 3.5 Catalysis of a reuse transition in the construction sector, conceptualised in Geels's (2002) framework.

Source: The authors.

This chapter first explained a wide variety of different aspects that need to be catalysed in order to make deconstruction and reuse happen in the context of pilots in the current niche, and second, needs for more general developments in the socio-technical regime to take place for the approach to spread and gain ground beyond the piloting phase. These needs entail not only key process steps and necessary tools and technologies, but also changes in behaviours and social institutions, such as knowledge, education, and regulation. Thereby, the key contribution of this chapter is in the analysis of the two main catalyst types, namely technological/design catalysts and societal/business catalysts, which interact in different temporal dimensions, the former being imminent targets and the latter more long-spanning goals of CE and here, in particular, circular construction. Figure 3.6 synthesises the various catalysts necessary for the sectoral change.

In terms of catalysts for pilots, manual tools are essential to make deconstruction and reuse feasible in practice, and digital technologies can be focal for ensuring a smooth and cost-efficient process. Nevertheless, the question is not of totally novel and unforeseen hardware or software. Rather, existing tools and technologies, developed for a different context, are applied on the deconstruction-reuse value chain in a novel process and adapted for this specific use. For instance, the quality inspection of elements can draw from the condition investigation of buildings; the deconstruction of elements is informed by the decommissioning of industrial production lines; and the logistics of elements can capitalise on the tracking of products in other industries, to name just a few examples. Making the existing tools even more suitable for deconstruction and reuse requires an evolution in practice. Building Information Modelling (BIM) is a good example: the existing BIM software is optimised for new production but could be adjusted for donor building inventory modelling and for design using reused elements with the help of add-on software and real-time object libraries available online. These notions match Geels's (2002) argument that regime transitions are rather gradual reconfigurations than sudden in nature.

Consequently, process innovations are at the core of the reuse transition, for both the pilot projects and the wider deployment. This includes not only practical design and production/construction processes and rules but also regulatory ones and how construction is managed as a business. Demolishers, architects, and engineers need to reconfigure their skills into novel work processes throughout the value chain in order for the sector to come up with new services, such as deconstruction, quality inspection, and design services out of reused elements. The same applies to element manufacturers and their new products, such as quality-assured factory-refurbished elements. The change of the socio-technical landscape is already manifesting at the regime level in building codes and company policies striving for carbon neutrality and circularity. Riding along this wave, there is now a chance to demonstrate the environmental benefits of reuse, have it acknowledged in legislation and incorporated in relevant education providers' curricula, and to uncover how to extract economic value from it. This applies not only in ReCreate's piloting countries but beyond them; necessary changes to the regime can be intentionally catalysed by sharing knowledge openly.

While ReCreate's pilots examine how to add on and hybridise with other sustainable construction methods, expanding into other markets beyond the project will be decisive as to whether, in Geels's (2002) terms, a successful niche-cumulation of reuse will lead to a transformed construction sector across Europe. The need for the construction industry to change is global, though. As concrete is the most used construction material in the world and the use of precast elements is also globally widespread, many practical contributions drawn from ReCreate's pilots will likely be applicable on other continents, too. Moreover, in contexts where other materials and forms of construction are more prevailing, the general framework presented in this conceptual chapter

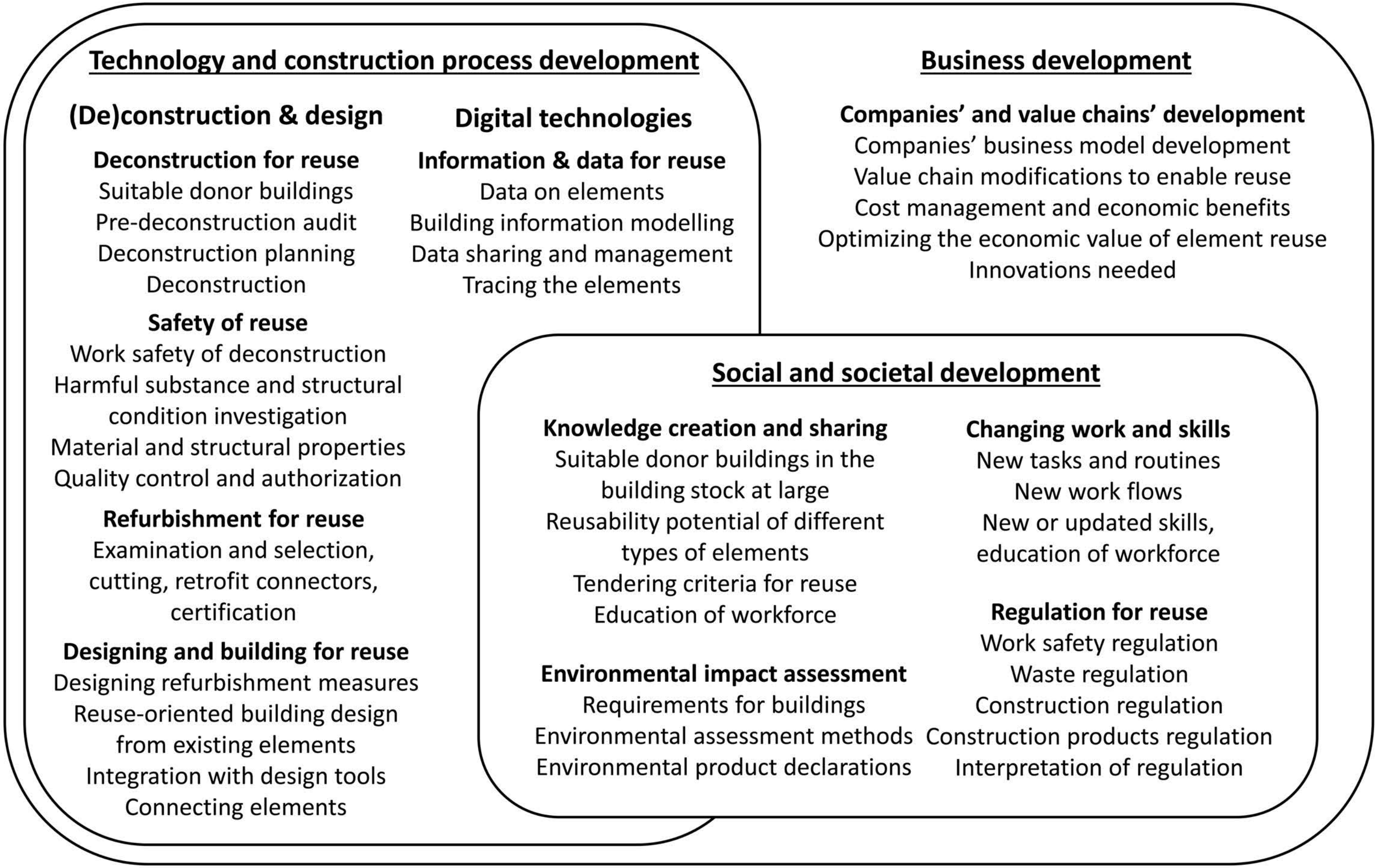

Figure 3.6 Diverse catalysts needed to transition the construction sector towards reuse.

Source: The authors.

may still be used as a tool for catalysing the construction sector's sustainability transition, even if other types and methods of circular construction are to be catalysed.

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Educational content

What categories of catalysts can be identified for a circularity transition in the construction sector? Name a few catalysts for each category and discuss their nature, role, and significance.

Considering the intertwined nature of factors in socio-technical regimes, such as the construction sector, reflect and elaborate on the potential linkages of a singular catalyst to other catalysts.

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