Hanke toteutetaan Euroopan Unionin REACT-EU EAKR-rahoituksella
ja rahoitus on osa Euroopan Unionin covid-19-pandemian johdosta toteuttamia toimia.

Vipuvoimaa EU:lta 2014–2020

Euroopan unioni
Euroopan aluekehitysrahasto

Uudenmaan liitto
Nylands förbund

KETO
Kestävän kasvun kehitysympäristöjen toteutuspolku

KETO WP4 - Activity 1

Circular Building Showcase

An Opportunity Map and Blueprint

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CIRCULAR BUILDING SHOWCASE
An Opportunity Map and Blueprint

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Version	Status and/or changes	Date
1.0	Final version	31.08.2023

Abstract & Context

This research provides a proposal for a real-life experimental house. The proposal is based on both a theoretical state of art of the circular economy (CE) in the built environment through a literature study, as well as a practical state of art through an opportunity map. The opportunity map may also be used as a stand-alone database and includes a variety of examples from practice in the following categories (1) realized buildings, (2) materials, (3) R&D projects (both completed and ongoing), and (4) realized pilots. The observations of the opportunity map and literature study ultimately lead to the proposal for a real-life experimental house and provide certain guidelines and areas of interest.

The proposed circular experimental house would address the main barriers hindering the adoption of the CE in the built environment that are identified in this report: (1) lack of awareness, (2) lack of education, (3) lack of knowledge, (4) lack of procedures, and (5) lack of market. It would do so in an interactive way with active involvement of the built environment supply chain.

This report is part of Work Package 4 of the "Implementation paths and environment for sustainable growth and development" project (KETO). The project is carried out by the city of Espoo, VTT, Aalto University and Omnia, and creates the conditions for a research and development environment for sustainable solutions in the Kiviruukki area in Espoo. With the help of the project, the goals of Finland's sustainable growth program on strengthening private and public partnerships and developing research infrastructure towards the growing markets of the green transition and digitalization are promoted. The project strengthens development environments where cities, companies, research and educational organizations, and residents can jointly develop, implement, test and pilot new solutions for the green transition.

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1. Introduction

In recent years the circular economy (CE) has found its place in many organizations' and governments' sustainability programmes and strategies. This is also the case in Finland where the objective is to transform the national economy in such a way that is based on the principles of the circular economy by 2035 (Ympäristöministeriö, 2021). At the same time, Finland is currently lagging behind this target, especially in industries that are primary consumers of raw materials, such as the construction industry (Valtioneuvosto, 2023). For Finland especially, increasing the resource productivity and circular economy of materials are deemed important points of action (Valtioneuvosto, 2023).

It is against this background that this report for a circular showcase for the construction industry as part of work package 4 of the KETO-project is written. To maximize the effectiveness and impact of such a showcase, this report will research the current status of CE adoption in the construction industry. The main questions under investigation are; what has been done so far, what actions are being undertaken currently, and perhaps most importantly, what is not yet done that should be done in order to speed up the uptake of the circular economy in the construction industry. In short, what would the circular showcase need to include in order to answer these questions?

The final result of the investigations presented in this report will yield a description of the circular showcase, as such forming the blueprint for its future realization. Before that, the next chapter will first focus on a literature review of CE in the built environment, followed by a problem statement and a description of the research design & methods in chapters 3 and 4. Chapter 5 will present an opportunity map for the circular showcase in four different domains; buildings, materials, R&D-projects, and pilots. The findings from the opportunity map are discussed in chapter 6, resulting in the blueprint for a circular showcase in chapter 7, followed by concluding remarks and recommendations in chapter 8.

2. Circular Economy in the Built Environment – Literature Review

Circular economy is a techno-economic model for production and consumption that is cyclic, restorative, and regenerative by intention and design (Kivikytö-Reponen (Ed.), 2022). This can be enabled by different strategies, for example sharing, leasing, reusing, refurbishing, and recycling existing materials and products. Thereby extending the life cycle of products and keeping the materials and their embedded value in the economy, while minimizing or eliminating the produced waste (European Parliament, 2022).

Although interest in the concept has increased significantly after publications by the Ellen MacArthur Foundation (2013), it has a longer history (Lieder & Rashid, 2016; Winans et al., 2017) and combines what we may refer to as cradle-to-cradle (C2C) thinking (Braungart & McDonough, 2002; Kristinsson et al., 2001; Stahel, 1982) with economic incentive alignment (Stahel, 2006, 2016). The combination of different, existing concepts has led to ambiguity about the exact definition of the circular economy that continues to be the topic of debate today (Kirchher et al., 2017). Given the practical aim of this research, an attempt at presenting an own definition will not be made. Neither will this research use an explicit, existing definition in order to avoid unnecessary contesting of the approach and research presented here.

This research does however adhere to the thinking in two different material loops, one consisting of 'biological' nutrients and one consisting of 'technical' nutrients (Piscicelli et al., 2016), where there is a hierarchical order of actions which are either more or less circular according to the 9R-framework (Potting et al., 2016).

2.1 Material impact of the built environment

Realizing a circular economy in the built environment is particularly important as the sector is one of the largest consumers of resources and energy, and one of the largest producers of waste. Estimates concerning the relevant numbers vary depending on the scope and definitions used, but it is mentioned that the built environment is responsible for 39% of global carbon emissions (UNEP, 2017), around 35-40% of global energy use (UNEP, 2009 & 2017), 30% of global raw material use (UNEP, 2009), and 46% of EU generated waste (Gálvez-Martos et al., 2018). The emissions present in the built environment can be divided further in emissions embodied in buildings through their constituent materials and the emissions occurring during the operational phase of buildings. Concerning the existing building stock, operational emissions account for around 75-80% of total emissions, whereas for new-build construction, operational emissions contribute around 50-55% to the total amount of emissions, with a higher amount (45-50%) of embodied emissions (Röck et al., 2020).

This somewhat paradoxical effect occurs since newer buildings are more energy efficient than older buildings, placing greater emphasis on the embodied energy and thereby the materials used during the construction phase (Röck et al., 2020). This enlarges the importance of conscious material and product choices during design and construction activities. Likewise, a large amount of emissions related to the current stock in the built environment could arguably only be reduced externally, by transforming our energy supply to a renewables-based system.

A closer look at the materials used in the built environment shows that the sector is a major consumer of bulk products like concrete, steel, and aluminium (Herczeg et al., 2014; Liu et al., 2012; Müller et al., 2011; Pauliuk et al., 2013). Rare earth materials are present only in lower concentrations in buildings, but due to the large amount of buildings, the total amount of these materials locked in buildings might accrue to significant amounts (Royal Institution of Chartered Surveyors., 2011). Also, the presence of rare earth materials will likely rise in the future because buildings are continuously becoming more 'intelligent', which i.e., means that they are increasingly supported by technological hardware that does consume these materials (Royal Institution of Chartered Surveyors., 2011).

Forecasts containing the future demand for material use in the industry are often focused on local markets or only include specific products. More general, higher-level studies are rare and prone to data availability sensitivities. Notwithstanding these difficulties, Deetman et al. (2020) made an attempt to forecast future resource use in the built environment. Their analysis reveals that resource use related to the built environment will continue to increase in most parts of the world until 2050, where global demand is increasingly influenced by developing countries. A continued rise in demand for resources, linked with an insufficient inflow of materials originating from the existing building stock means that reaching 100% circularity in the built environment will not be possible, even if waste production no longer takes place in the sector (Deetman et al., 2020).

Finland, and Europe in general, is a continent that is low on resources and resource production (European Commission, 2021). Concerning the above observations, attracting the needed resources and materials for the built environment will be met with increasing competition from other parts of the world. This, linked with recent events that revealed volatilities in the global supply chain (e.g., COVID-19 pandemic), and energy supply (e.g., war in Ukraine), means that investing in circularity in general (and in the built environment), is also investing in the robustness of future supply chains, which is acknowledged by the European Commission in its New Industrial Strategy for Europe (European Parliament, 2020).

2.2 Circular design

It is estimated that up to 80% of products' costs and environmental impact are determined during the design phase, and poor decisions made early in this phase are often hard to reverse afterwards (European Commission, 2020). Thus, the core of designs should be circular and sustainable. Circular design has the potential to create value in multiple ways (Bocken et al., 2016; Metabolic, 2022):

- decreased negative environmental impact (fewer virgin materials needed),
- increased lifetime (flexibility, adaptability and modularity of spaces and structures),
- decreased demolition and recycling costs (detachability and movability of components and structures)
- securing supply and material availability (fewer critical raw materials needed).

Academics have presented circular design frameworks and methods already in numbers (Dokter et al., 2021) and various toolkits with case studies are freely accessible (Circular Design Toolkit, 2023; d.Hub, 2023; Ellen MacArthur Foundation, 2022; Metabolic, 2022; Rijkswaterstaat, 2020; Kivikytö-Reponen (Ed.), 2022). However, a vast number of studies regarding the construction industry are still conceptual (Dokter et al, 2021). Nußholz et al. (2023) even find that there are no academic studies covering the impact of cases where materials and components are reused from existing and to be demolished buildings.

In grey literature examples of circular case studies and pilot projects can however be found, these range from:

- Cases where constructions are made of movable and reusable structures, and flexible, modular structures, either completely or to some degree e.g., the temporary district courthouse (Metabolic, 2022) and the Circl pavilion (Circl, 2017) both in Amsterdam, The Netherlands, and the floating office in Rotterdam, The Netherlands (Powerhouse, 2023).
- Cases where an existing building was disassembled and rebuilt e.g., Cargo Building 18 at Schiphol Airport, The Netherlands (Schiphol, 2020) and temporary market hall in Stockholm, Sweden (Metsä Wood, 2022).
- Cases where a current building was adapted with 'harvested' materials originating from a different building e.g., K.118 in Winterthur, Switzerland (Baubüro in situ, 2021).
- Cases where components are completely or to some degree reusable e.g., drywalls and use of recycled concrete (Rijkswaterstaat, 2020), and reusable steel and concrete elements (Yrjölä, 2022).

2.3 CE adoption in the Built environment and Construction Industry

However, despite the large interest by scholars and industry, mass adoption of circular design in the construction industry and built environment has not (yet) taken place (Çetin et al., 2020). This has sparked interest by scholars to investigate the barriers hindering the adoption, and possible drivers that could facilitate, the uptake of circular solutions in the construction industry and the built environment. There are many examples in literature focusing on these barriers and drivers. Each study however departs from a different point of view, yielding different results, decreasing comparability amongst each other. Bilal et al. (2020) for example, focus on barriers found in developing countries, and source CE barriers based on a literature review and expert interviews. Chen et al. (2022) attempt to tackle the barrier and driver problem by undertaking a literature review and sorting the identified topics according to the way the construction supply chain is organized. Hart et al. (2019), take a different approach again, where the results from a literature review are categorized as being either cultural, regulatory, financial, sectoral, or cultural. It is worth noting that, due to the lack of practical adoption of the concept, most barriers and drivers identified are of a theoretical nature and have a relatively high abstraction level. Real-world knowledge accumulation of CE in the built environment is limited (Nußholz et al., 2023), and studies that systematically gather practically gained knowledge are limited, with Kanters (2020) being a notable exception when it comes to the European context.

Given the abundance of existing studies on drivers and barriers, and of state of art studies summarizing those, this research will not make an attempt at knowledge creation through a continuation of those literature reviews. Because the aim of this research is of a more practical nature, we will suffice here with several, non-exhaustive, barriers and drivers as identified in the current literature body. The focus is on those barriers and drivers that have a direct impact upon the type of experimental case study that that this research aims towards, i.e., on barriers and drivers closely related to the design and construction process, where the drivers are assumed to be actions needed to overturn the described barriers.

Firstly, the lack of large-scale adoption of CE in the built environment might be partially explained by the vague definition of the circular economy and variance of possible (combinations of) circular design strategies (Kirchherr et al., 2017; Chen et al., 2022). Given the vagueness of the concept, it is perhaps unsurprising that indicators to measure circularity are insufficiently established (Bilal et al., 2020; Moraga et al., 2019), making it difficult to measure the effectiveness of projects in terms of circularity. Current efforts for standardization are however underway (ISO, 2023) and may offer opportunities to measure/standardize circularity over multiple projects and improve feedback on the effectiveness of circular design.

Secondly, with the implementation of circular economy in the construction industry, several specific sectoral conflicts could arise due to the long lifespans, numerous stakeholders, and many components and materials involved in construction projects (Hart et al., 2019). Examples of conflicts or trade-offs in a circular construction industry are: structural integrity vs. ease of disassembly; longevity vs. flexibility; ‘simple’ vs. composite products; and renovation vs. new build (European Commission, 2020). These conflicts or trade-offs usually arise between different stakeholders that have their own incentives and who are rarely involved throughout the whole building lifecycle (Debacker et al., 2017).

Thirdly, there seems to be a lack of established procedures/ways of working regarding the circular economy in the construction industry. It is well understood that in a circular construction industry, the design needs to allow for the dismantling of its constituent components (Hart et al., 2019; Nußholz et al., 2023). And even if there has been attention to design for disassembly in literature, there are as of yet no standard solutions for re-using building materials, and their quality assessment. The ability to receive warranties for these materials is therefore uncertain (Chen et al., 2022).

Fourthly, lack of awareness and education or the needed skills to realize a circular built environment are frequently mentioned in literature (Bilal et al., 2020; Chen et al., 2022; Çetin et al, 2020). Kanters (2020) affirmed this aspect through expert-interviews and added that specifically in-depth knowledge about (1) materials, (2) construction, and (3) the ability to work flexibly are currently missing in the design process.

Finally, there is consensus in literature that there is no functioning market for circular construction materials at the moment, and that this should be developed (Bilal et al., 2020; Chen et al., 2022, Hart et al., 2019; Kanters, 2020; Nußholz et al., 2023; Çetin et al., 2020). In this regard, it should be noted that substantial efforts have already been undertaken to establish the basics needed for a functional circular construction material marketplace. In particular improvement of collaboration and information flows (aided by data and digital technologies) have received attention as a possible “backbone of the circular construction industry” (European Commission, 2023). Also, digital twins and materials passports are proposed as supportive tools for optimizing the lifecycles and transfer of data to users and maintenance (Dokter et al., 2021; European Commission, 2020; European Commission, 2023). Solutions integrating digital twins and product data to existing BIM software are already piloted in the EU (CircularEcoBIM, 2022), while new paradigms as ‘buildings as material banks’, enabled by materials passports, have been suggested and researched to realize the circular economy in construction (Aguiar et al., 2019; Geldermans, 2016; Debacker &

Manshoven, 2016). However, as stated above, despite the attention given to the foundations of marketplaces (i.e., enabling information flows and availability amongst stakeholders), the actual marketplaces themselves have not become commonplace yet.

3. Problem statement

Following the previous section, we can establish that mass scale adoption of circular economy in the construction industry and the built environment has not (yet) taken place, even though the current adverse environmental impacts of the sector are significant, and there is a general idea of the potential of circular design to (at least partly) overcome these issues. Best practices can be found through the case studies, but the associated lessons learned are not recorded systematically and actively shared along the value chain.

In short, the following aspects are hindering large-scale adoption of the circular economy in the construction industry:

1. **Lack of awareness** > There are some solutions, but best practices are not systematically recorded and shared.
2. **Lack of education** > The needed skills for a circular construction industry are not available in the current market.
3. **Lack of knowledge** > There are no uniform solutions for products to be re-used (dismantlability, remantlability).
4. **Lack of procedures** > There are no standards describing how to uniformly assess the quality of products to be re-used.
5. **Lack of market** > There is some groundwork related to market enablers done, at present there are however no functioning markets.

4. Research Design & Methods

The research presented in this report aims to create a blueprint based upon an opportunity map (practical state of art), and a literature review (theoretical state of art). The opportunity map may be used as a stand-alone database for further use.

The main research question of this report is: How to realize a circular showcase in such a way that this provides the groundwork for industry-wide adoption of circular solutions in the built environment?

To be able to answer the main research question, the following sub-questions need to be answered:

1. What circular economic activities have already been undertaken in the built environment?
    a. Concerning buildings
    b. Concerning materials and components
    c. Considering R&D-projects
2. What circular economic activities have not yet been undertaken in the built environment?
    a. Concerning buildings
    b. Concerning materials and components
    c. Considering R&D-projects
3. What lessons can be learned from the answers to sub-questions 1 and 2?

The literature review (as part of desk-research, following Robson & McCartan (2016)) was presented in the previous section. The selection of articles to be included in the literature review has been sourced through the Scopus database based on search strings related to the key topics of the literature review:

1. Definition of circular economy in the built environment
2. Material impact of the built environment
3. Circular design
4. Adoption of circular economy in the built environment

Snowballing (Wohlin, 2014) has been used to assess both the relevance of found articles, as well as possible other relevant articles.

The input for the opportunity map has come from:

1. Sources obtained through the snowballing process of the literature review
2. Online searches related to materials found through the literature review snowballing process, as such forming a second iteration of the snowballing process.

Details regarding data processing procedures for specific categories of the opportunity map are described separately for each category (see appendices A-D). Limitations regarding this approach are described in chapter 5.

5. Circular Economy in the Built Environment – Opportunity Map

This chapter will present an opportunity map for the circular economy in the built environment. The purpose of the opportunity map is twofold. Firstly, the opportunity map will gather the existing status of CE in the built environment, which will enable identification of those topics that are of interest to pursue further for the circular showcase. Secondly, it can be accessed as a stand-alone database (see appendices A-D) by anybody who is looking for circular examples of buildings, materials, R&D-projects and pilots, regardless of the further aims of this particular research.

Four different types of examples are included in the opportunity map. The first section focuses on realized buildings, and the second section focuses on materials (see appendices A&B). This is because of the typical relationship between materials and buildings, where the building can be seen as a collection of different components (or materials) that together form an entity that can be described as a building. A building is as such a collection of interrelated parts or components(/materials) at different scale levels (adapted from Prins, 1992). Therefore, distinguishing between available solutions at a building and at a material level is useful for the opportunity map. The third section covers R&D-projects, and the fourth section focuses on realized CE pilots in the built environment (see appendices C&D).

The remaining paragraphs of this chapter will present the findings from analyses of the different opportunity map categories. In general it needs to be noted that, even if care was given to generate a representable sample for each of the included categories, the opportunity map is of a qualitative nature and the data gathered here is therefore not exhaustive. Even if the author views the opportunity map as representative of the current state of art, it is still necessary to take this limitation into account when using the opportunity map. Further, category specific considerations regarding the data will be presented in the following, category specific paragraphs.

5.1 Solutions for buildings

After identifying in section 2.4 that there is no abundance of realized CE case studies in the built environment, this section will make use of a recent study by Nußholz et al. (2023), who have mapped several relevant case studies. The authors of that paper originate from different European countries and have significant history in publishing about the topic of CE in the built environment, which further enhances the relevance and validity of the featured case-studies as a recent state-of-art. To increase the sample size of case studies, a look is also given here to a list of case studies of flexible buildings made by Moos Heunicke & Vejlgaard (2021) in the CIRCuIT project. Even though this study primarily aimed to map Design for Disassembly (DfD) compliant projects, an analysis (which will be described below) shows that a selection of these projects is to a high degree compatible with CE strategies (the exact reasons for data in- or exclusion of the sources described above can be found in appendix A). This data gathering strategy has resulted in a significantly larger sample size.

The opportunity map contains 56 buildings throughout Europe, with the largest concentration of cases in The Netherlands. Also, a significant amount of cases is located in the United Kingdom, Germany, Denmark, and France (see figure 1).

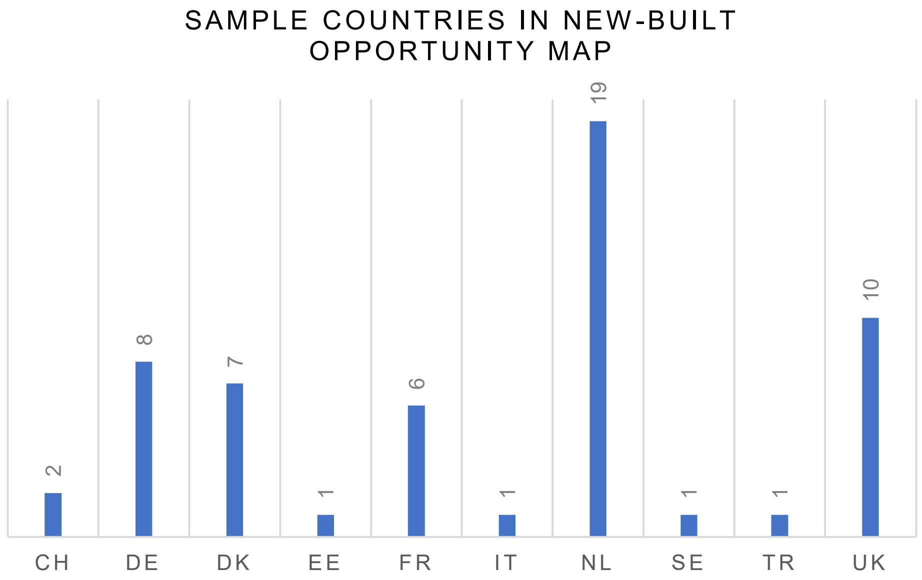

Figure 1: Sample countries of case studies included in the new-built opportunity map (own image)

The average weighted age of the case studies included in the sample is 14,8 years, which approximately translates to 2008 as year of construction. However, the average is heavily skewed, as 73% of the included cases was built after 2008, with a mode-age of 4 years (which corresponds to 2019 as year of construction). Furthermore, most of the included cases (70%) are between 2-15 years of age.

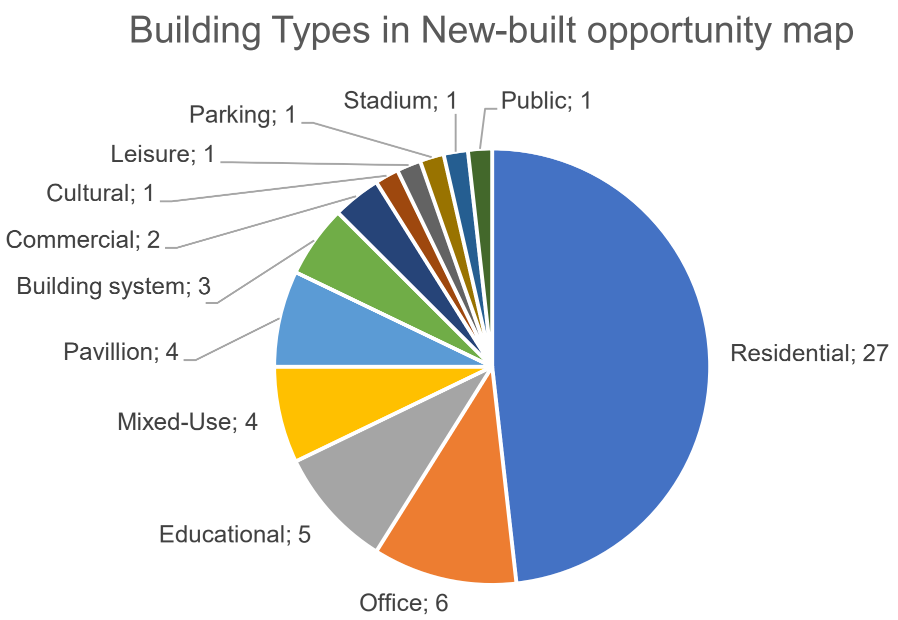

Figure 2: Building types present in new-built opportunity map (own image)

A look at the distribution by building type of the included case-studies shows that a variety of different building types are included in the sample (see figure 2). However, a strong emphasis on residential objects (n=27) can be found, representing nearly half of the sample size. Furthermore, by taking a closer look at the objects, it can be argued that for 16 of the case studies (29%), some sort of public or societal endorsement can be found (e.g., public building, social housing). Further categories that stand out here are pavilions (n=4) and building systems (n=3), since they don't represent 'typical' objects in the built environment. If these would be excluded from the sample, it can be argued that the remaining majority sample (59%) represents 'ordinary' building types, enhancing the validity of the sample as representative of the built environment. If the largest category of residential objects is broken down further, it becomes apparent that from a total of 27 cases, 10 represent multi-family dwellings, 2 represent attached single-family dwellings, and 15 represent detached single-family dwellings. This last category can be broken down further into dwelling size, revealing that the majority of cases here (n=8) represent dwellings of an average European size, with only 2 cases in the micro (<50m2) category, and 5 cases in the large (>125m2) category. All in all, the cases present a well-mixed, representative sample of different building types in Europe.

Analysis also shows that technically flexible DfD-buildings show compliance with circular building strategies (see appendix A). This compliance was found for 42 out of 43 cases, meaning that these objects are circular to some degree. 41 out of 43 cases show consideration of a circular 'out'-scenario, which is unsurprising considering that these particular objects were engineered to be able to be disassembled. More surprising is the fact that half (n=15) of the DfD-buildings that does not consider itself as a circular object (n=30), still considered circular 'in'-scenarios, making this a very relevant reference category for future CE in built environment studies.

If on the other hand CE buildings that were identified in Nußholz et al. (2023) (n=11) are compared to technical DfD aspects, only 4 cases that fit with technical DfD-principles are found. Another 2 cases fit with spatial DfD-principles instead of technical DfD-principles, and the remaining 4 cases do not fit with either DfD-category. This implies that the relationship between technical DfD and CE buildings identified here is not necessarily valid both ways. Furthermore, only 4 out of 11 cases consider a circular 'out'-scenario. In practice this means that care was given in realizing the project in a circular way, but that less thought has been given to the end-of-life scenario of these buildings.

Another interesting observation is the fact that of the 39 objects that considered an 'out'-scenario, only 5 have actually been dismantled (this sample of 39 objects excludes 10 objects with status 'Unknown'). Of the 5 dismantled buildings, 2 were pavilions with a very short expected lifetime (basically the duration of the associated exhibition), 1 has been destroyed by fire rendering it unusable, 1 stadium specifically built to last for 1 event and a public building which was replaced by a newer, permanent building. In all other cases, regardless of building age, no use has been made of the object's dismantlability. Most extreme examples (by age) in the opportunity map are the Prouvé houses in Paris that are still standing today and very popular as places to live. When it comes to offices, Project XX (which is well beyond its designed 20-year lifetime) is still operational, with no current plans of dismantling it. Also, Ladywell and Wood Nursery, which were both built to be disassembled in 5 and 2 years respectively, are still standing. In both cases due to (1) their own operational success, and (2) lack of development of replacement buildings. The latter reveals the intricacies involved in the real estate market to enable actual dismantling of buildings. An example from the Kersenboogaard case shows that even if clients/owners are aware of dismantling opportunities, they might consciously choose not to use this option.

When it comes to structural systems used in circular buildings, there does not seem to be one system that is preferred over others. What does become clear is that for circular buildings concerning both 'in' and 'out' scenarios, the box-system is often used (n=7). Column/Beam configurations appear frequently regardless of whether 'in', 'out', or both scenarios are considered. However, Column/Beam configurations are most frequent in buildings considering 'out'-scenarios (n=11), which might be linked with the fact that many DfD-objects were erected in steel, where such a configuration is common.

In this sample, 7 objects considering an 'out'-scenario were erected in steel, making that the most frequently used material in that category. In buildings considering both 'in' and 'out'-scenarios timber is the most-used structural material (n=15), followed by hybrid systems (n=7). The hybrid systems in this sample usually concern either a combination of timber with either steel or concrete elements, making timber even more present in this category. Also noteworthy in all categories is the lack of materials other than 'traditional' timber, concrete, and steel. Only two examples of new structural materials (cork and hempcrete) can be found in this sample.

5.2 Solutions for materials

For the categorization of the materials opportunity map, the 'shearing layers' concept introduced by Brand (1994) is used (see figure 3). The shearing layers approach has been applied frequently in a circular economic context, even if this was not the original purpose of the concept. The power of the shearing layers concept is that it allows readers to (1) get acquainted with the fact that a building is constituted of different elements/components/materials in different categories or layers, and (2) that these different categories may have different associated lifetimes. Even if applying the shearing layers concept here includes some risk of arbitrary placement of components in a certain layer, or a divergent general lifetime of components as to those mentioned in the original concept, these are considered justified given the listed advantages. Please note that the 'Site'-layer is not included in the opportunity map, as it was not possible to gather information for this specific layer.

Figure 3: Brand's (1994) shearing layer concept that divides a building into several layers, which have a somewhat common aggregated lifetime (own image).

A total of 52 materials have been included in the materials opportunity map (see appendix B). The distribution of materials according to type is fairly even between the different categories (biodegradable, traditional, hybrid and innovative). The real-world application of 42 of the included materials has been verified, 6 materials are still in the development phase, and for the remaining 3 materials the status is unknown. Roughly 40% of the included materials considers both circular 'in' and 'out' scenarios, 35% considers circular 'out' scenarios and the approximately remaining quarter considers circular 'in' scenarios. The opportunity map therefore consists of a varied sample of different available circular material options in Europe. Limitations to the representativeness of the opportunity map are the relatively focused geographical origins of the materials presented (mainly Belgium, France, and The Netherlands), and an uneven spread of the number of materials included per building layer. This has to be considered in any conclusions and/or recommendations based on this opportunity map. Notwithstanding these limitations, the opportunity map gives a relevant impression of the currently available (types of) circular material solutions.

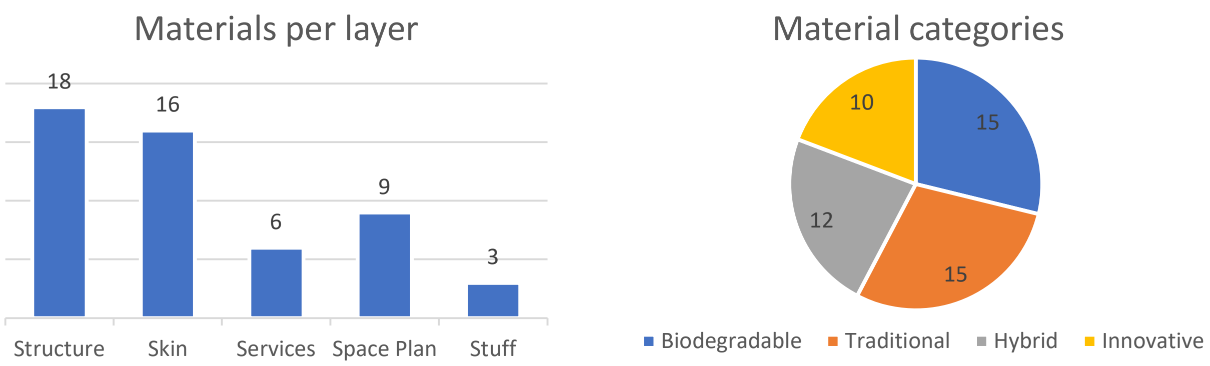

Figure 4: Number of materials per layer & the share of different material categories present in the opportunity map (own image).

A closer look reveals that the majority of included materials have been identified as belonging to either the structure or skin layers (see figure 4). When the material categories are analyzed further for each layer, it can be seen that biodegradable and hybrid materials form the majority of included materials in the structural layer. Concerning the skin layer, most materials fall in either the traditional or innovative category. These differences are explained by the relatively large number of wood-based solutions included in the structure layer (which is included in the biodegradable category, n=9 out of a total of 18 materials in this layer), and the presence of structural systems that use two or more materials (as these qualify as hybrid solutions). Whereas the materials in the skin layer more often concern re-used traditional materials (e.g., re-used bricks), and the number of innovative materials in this layer is largely explained by different types of insulation materials. In the remaining layers the distribution of material categories is more even without big outliers.

When it comes to the possibilities for application of the materials in different higher level circular strategies, the majority of presented solutions can be applied in ‘slowing’ and/or ‘closing’ strategies. Also application in ‘regeneration’ strategies is quite often possible. Only one identified solution can be applied in ‘narrowing’ strategies. On a lower level, it can be seen that out of possible design related strategies for the structure layer; ‘design optimization’, ‘dematerialization and lightweight construction’, ‘design for reversibility’, and ‘design for reuse’ are strongly represented (n=7-8), and that when it comes to material selection, all solutions in this layer (n=16) focus on ‘avoiding or reusing (carbon-intensive) components’. This reflects the strong presence of different structural systems in the opportunity map in this category, as well as the fact that the structural layer usually holds the largest number of carbon-intensive components in buildings. The presence of different structural systems in the map is furthermore confirmed by the focus on ‘resource efficiency during construction’ and ‘low-carbon construction equipment’ in this layer (n=7-8).

For the possible design strategies related to the skin layer, the earlier observations made regarding material categories and types are confirmed here with the frequent occurrence of ‘secondary materials and components’ (n=8), also ‘design for reversibility’ has a strong presence here (n=8). On the services layer ‘design for reversibility’ (n=6) and ‘design for reuse’ (n=4) are the most frequently occurring strategies. The services layer is also the only layer where the ‘improve operational efficiency’ strategy can be found. This can be explained by the fact that several solutions offered here aim to enable a better operational efficiency for the buildings where these are applied. For the space plan layer there do not seem to be certain strategies that are preferred over other ones, while on the stuff layer ‘secondary materials and components’ (n=3) appears most often.

When a look is given to the different scenarios for each layer, it can be seen that slightly more than half of the presented solutions on the structure layer consider ‘out’ scenarios, signaling room for improvement. Furthermore, all solutions presented for the services layer only consider ‘out’ scenarios. The development of products and/or materials for this layer that consider ‘in’ scenarios therefore seems to be lacking.

5.3 Ongoing and completed R&D-efforts

As mentioned previously there is and has been significant interest in circular economy in the built environment by scholars as well. This paragraph aims to map R&D-projects and their lessons learned, as well as current actions undertaken in research projects. The aim is to prevent future efforts from doing the same work twice in light of the pursued case-study here. The geographical scope of the projects included in the map is mostly Finnish (accompanied with several European studies with a primary focus outside of Finland, but for which the results are deemed relevant).

In total 20 different research projects have been reviewed (see appendix C), 11 of which have been completed and 9 of which are ongoing. The majority of these projects consider both circular ‘in’ and ‘out’ scenarios (n=16), three projects consider circular ‘in’ scenarios and for one project the scenario scope is unknown. These numbers signal that the general approach in research projects considers the whole loop of the objects under investigation.

When a look is given to the scope of the research projects, it can be seen that the majority of these have a focus on a ‘management’ or strategical level (n=14), 5 of these projects also consider material aspects on 1 or more Brand layers. This means that most projects consider a relatively high abstraction level, which is reflected by the outcomes of the projects, where 20 out of 30 listed outcomes are either guides/instructions (n=7), management demonstrations (n=4), an ecosystem (n=3), business model description (n=3), roadmap (n=2), or data platform (n=1). Guides/instructions most often describe different methods for pre-demolition audits and/or inventories.

Of the listed outcomes, 8 out of 30 considered materials. Half of these projects (n=4) take a detailed view of a certain material (wood, ceramics, mineral wool, concrete) in a recovery or reuse scenario. In all of these projects both companies operating in the value chain, as well as research partners are involved. The other half of the projects that considered materials (n=4) do so from a wider perspective and include materials on different layers and in different scenarios, for which different opportunities are demonstrated through real-life demonstrations and/or pilots. Of the finished projects, this concerns both the BAMB and Super Circular Estate Project. For the ongoing projects, similar efforts are undertaken in the FCBRE and CityLoops project.

While the lessons learned of all research projects are relevant, the efforts and outcomes of the latter projects are particularly relevant to this study due to their focus on real-life implementation of solutions. The outcomes of the BAMB project will be discussed in the paragraph on pilots below (three out of four pilots are deemed relevant for this study and have therefore been reviewed). Super Circular Estate Project has researched the dismantling of an old apartment building and the application of the recovered materials in different pilot buildings. Also the economic feasibility of such operations was taken into account, which revealed that economic viability of the researched opportunities was low.

Of the ongoing projects, the CityLoops project in Mikkeli (Finland), focuses on systematic mapping and inventory creation of to be recovered materials from an old hospital (which has so far yielded an audit map), and the subsequent possibilities of reuse in new projects. The FCBRE project concerns a collective effort to increase the amount of reclaimed building elements in Northwestern Europe. Creating opportunity maps, reclamation audit methods, and element catalogues. Specific parts of these project outcomes have been the subject of investigation of the 37 pilots undertaken in the project. Even though these pilots themselves are diverse in size and stakeholders involved, the scope of operations is always the dismantling, reuse, and/or redevelopment of the pilots under investigation. As such, the scope of the materials involved is ‘traditional’.

5.4 Realized pilots

For the pilot opportunity map, four 'whole building' pilots were reviewed (see appendix D). As mentioned in the previous paragraph, three of these were realized as part of the BAMB research project. The pilots show a wide diversity of circular strategies applied, and all consider both circular 'in' and 'out' scenarios. For two of the pilot buildings it is unknown whether they have been disassembled, for one this has not been done. The remaining pilot has been disassembled and reassembled annually three times. All pilots are built according to a column/beam system, even if the main structural material is different between the pilots (steel (2x), timber, and concrete).

When it comes to CE categories of principles slowing and closing are found in all 4 pilots, narrowing is found in the Circular Retrofit Lab and B.R.I.C-pilots, while regenerating is only found in the latter. A look at the included circular building strategies reveals a focus on; 'design optimization', 'design for easy maintenance and repair', 'design for reversibility', and 'design for reuse', which are present in all four pilots. 'Design for durability and long-life', 'secondary materials and components', and 'waste prevention in construction' are strategies present in 3 out of 4 pilots.

Other circular building strategies that are present to a lesser extent include 'materials with low embodied carbon', 'avoidance of (carbon-intensive) components and structural elements', 'maintenance and repair with minimum resources', all n=2, and 'dematerialization and lightweight construction', and 'low-carbon construction equipment', both n=1. The amount of recurrence of different strategies seems to suggest a focus on dismantlability first, and secondly on different ways of waste prevention as a result of the construction activities.

6. Discussion

Following the findings presented in the previous chapter, it can be argued that technically flexible DfD-buildings may be considered references for circular projects, provided that these are evaluated in a similar way as was done for the opportunity map in this report (i.e. evaluation of their circular compliance on a case-by-case basis). This could lead to a significantly larger sample of available circular case-study buildings for CE in the built environment, as DfD has been researched over a longer period of time and therefore, a significant amount of realized case studies and literature are available (beyond those that have already been included in the opportunity map of this report). Furthermore, it can be argued that the disassembly learning curve will not be steep enough just by looking at cases from practice, as even buildings that are designed to be disassembled, are rarely disassembled in practice.

Also, there is a need to experiment with the implementation of newer, more sustainable, and efficient materials, as this is currently not being done in the buildings included in the opportunity map. Yet, the opportunity map for materials does show that these kinds of materials would potentially be available for implementation, signaling (1) some (as of yet) unknown barriers to wide market adoption (at least outside of the scope of this report), and (2) the potential for a test-site to demonstrate and research the capabilities of said materials. Notwithstanding the above, it needs to be noted that applications like the use of a certain percentage of aggregates and waste materials or slags in concrete products, is slowly becoming more common in the industry due to the adoption of certain demands in sustainability certification schemes like e.g. BREEAM (2023). Applying for sustainability remains of course voluntary and is not done for every new, to be renovated, or existing building.

From the evaluation of finalized and ongoing research efforts, it becomes clear that these efforts have so far mostly yielded either more general outcomes in the form of roadmaps and guides or instructions, or in-depth mapping of circular opportunities throughout value-chains for specific products. General, industry-wide applications of several materials have not been the focus of most of the studies in the opportunity map. Projects that have considered this to some degree, (like e.g., the CityLoops-project) have done this for single case studies, where lessons for the whole value-chain could be learned, but the ability to extrapolate these findings is not evident based on the small sample size. The same could be argued for the Super Circular Estate Project, where valuable lessons were learned, but in a restricted context that was not necessarily aimed at learning on a material level. However, important findings of that project to take into consideration in the circular showcase blueprint, are the economic viability and business case of the researched opportunities. These have so far not been taken into consideration separately in this report but proved to be a barrier to wide scale implementation of the case-study objects under investigation in the Super Circular Estate Project. As circular economy by definition links economic with sustainable considerations, this is aspect is something that should be taken into consideration in efforts following up on this report.

For the BAMB-project the most relevant lessons were learned through the undertaken case studies, and if the combination of the pilots as a whole is examined, most of the possible circular operations are covered. This is however not the case when the pilots are studied individually. B.R.I.C. has for instance focused on the possibilities of disassembly and reassembly with a certain, given amount of components. But there has not been a focus on material and product diversity in the set of components, even if the re-application of this set for various building functions has been innovative and educational. The Circular Retrofit Lab has focused on using several different materials, but these mostly concern the ‘space plan’ layer. For the other layers (e.g., skin), no disassembly has taken place after construction. Regarding the Circular Building a combination of the arguments above can be made. Also, the focus in these case studies has primarily been on either creating a functional or dedicated space, which is of course one of the primary objectives of buildings. However, experiments with materials itself in a way that would enable systemic material recirculation of a significant amount of different materials and/or components have not been the focal point of the pilots included in the opportunity map. For the GTB Lab on the other hand, the focus has been specifically on developing this ability, but in that case the final material selection has been limited.

The observations above seem to indicate a possibility for a showcase focusing on systemic material recirculation of a significant amount of different materials and/or components. Such a showcase should include frequent dis- and reassembly, and both re-used materials as well as newer, innovative materials, and combinations of those.

7. Blueprint for a Circular Showcase

This section will present the blueprint for the circular showcase, based on the findings of the previous chapters. A suggestion is made here to realize a real-life experimental building as the circular showcase, as this would enable structured research of the problems established in chapter 3, along with the further intricacies demonstrated in the opportunity map. The blueprint consists of research questions and methods, a description of the characteristics, certain layer-specific topics that should be researched, and the stakeholders involved in the experimental building. Also, a contextual umbrella is presented that captures the ideas of the experimental house to aid in further dissemination of the proposal.

7.1 Research questions and methods

The proposed main method is to develop a real-life experimental building, where the involved stakeholders will be able to experiment as to answer the identified sub-questions. The research method used here will strongly relate to action research (Robson & McCartan, 2016).

The main research question of the approach is: how to accelerate the adoption of the circular economy in the construction industry and the built environment?

To address the main research question several sub-questions need to be answered, which relate to the earlier identified gaps:

1. How to systematically record and share circular solutions and best practices?
2. How to enable the necessary skill attainment across the value-chain to be able to realize circular solutions?
3. How to identify uniform solutions for products to be re-used(/dismantled/remantled)?
4. How to uniformly assess the quality of products/components/materials to be re-used?
5. How to develop a functioning market for circular solutions in the built environment?

7.2 Experimental building, characteristics

On a building level, the experimental building should attempt to incorporate different structural systems and as much different materials as possible. This would allow research and learning of as many different topics on as little realized square meters as possible. Furthermore, the design should allow for disassembly of all materials and components involved.

The materials involved should be a combination of re-used materials and components from existing structures, as well as newer, innovative materials. For re-used components, the target should be to establish uniform procedures and solutions to enable industry-wide application of certain types of re-used materials and components. Apart from that main focus, a look could also be given to material side streams of other industries.

While the aim should be to maximize the re-use of existing materials and components, from the literature study it has become apparent that focusing on these alone is not enough, as there will not be sufficient re-used materials to meet the future construction demand. Involving new materials and components in the experimental building entails a risk that the emissions and climate impact related to the experimental house will be larger than it necessarily would need to be when these materials are not involved. As established earlier however, disassembly is rarely taking place in the industry, limiting knowledge accumulation of such solutions in particular. Therefore, considering the aim of the experimental building to realize change across the value chain, the surplus of environmental impact from these activities is deemed defendable when taking the targeted impact into account.

The environmental impact of the different elements and components constituting the experimental building should be measured in order to be able to research the potential impacts on an industry level. Established practices, such as life-cycle analysis (LCA), could provide a systematic way of measuring the environmental impact of the experimental house as a whole, as well as the individual materials and components.

Next to environmental measurements, also the performance of the materials and components in other relevant categories could be measured. For materials and components in the skin layer e.g., thermal performance and airtightness could be measured, for materials and components in the services layer e.g., energy performance could be measured. This would allow structured learning and development of those characteristics.

Finally, the experimental building should be dismantled with a certain frequency to allow possible new materials and components, or updates of existing components and materials to be researched in new configurations. This would arguably lead to a larger environmental impact, but the same argumentation presented earlier considering the newer materials is applicable here. In order not to lose knowledge while dismantling the experimental house, the applications of materials in different configurations should be captured in 'standard' construction details that can be attached to the materials and components and spread digitally through product libraries and BIM-models. Also the economic feasibility of such operations should be recorded as part of these activities.

7.3 Layer-specific topics

Considering that the structure layer usually exhibits the largest share of the emissions generated in construction projects, the main aim here should be to maximize re-use of materials and components. Furthermore, given that the main materials used in the structure layer of opportunity map were either steel, concrete, or wood, it would be relevant to experiment with innovative materials. Another angle here could be to research doing more with less (existing) materials, through e.g., new construction methods.

For the skin layer an emphasis could be placed upon maintenance and repair, as well as material innovation. This as the opportunity map shows that these are currently not considered for this layer, or when it comes to material innovation, mostly in terms of insulation materials, not of facades as a whole.

The opportunity map showed that on the services layer no materials or components are considering circular 'in' scenarios, making this an interesting area to research in the experimental house.

Both the space plan and stuff layer are more diverse in scope and possible solutions than the previous layers, and as a result also the solutions offered there are more diverse. No specific focal points arise from the opportunity map concerning these layers, but the experimental house should provide an opportunity to further develop solutions or new ideas for these layers as well.

7.4 Stakeholders involved

The construction value chain is fragmented and there will therefore be a significant amount of stakeholders involved in realizing the experimental house. With the aim of creating industry-wide solutions, it should also be an aim to involve as many different producers as possible. Even if previous paragraphs presented some focus areas, no producers should be excluded from partaking in the project. As their materials and products will be the object of the studies undertaken, and the complete collection of materials and components will form the design library.

As such, the design library will form the basis of the design of the experimental house. Preferably different design variants will be researched, examined, and evaluated based on their ability to provide answers to the research questions asked. Making use of digital design tools, and parametric design in particular, in this phase could assist in this evaluation and form an opportunity to transform design processes itself as well. In order to address the lack of education in the circular built environment, having design students involved in this phase (along with a certain amount of professionals) would be a valuable addition in reaching the goals of the experimental house.

For the realization and dismantling of the experimental house, it would for similar reasons be valuable to involve students of practice along with seasoned professionals.

7.5 Contextual umbrella

In order to help envision and explain the goals of the experimental house approach presented here to stakeholders from the value chain and other interested parties, the section below will present a contextual umbrella which captures the ideas of the experimental house for further dissemination of the proposal.

21st Century Experimental House

In the middle of the last century Finnish buildings and architecture conquered the world. With its modernistic and unique style, there was abundant experimenting using the new materials of that age (e.g., concrete). Perhaps one of the best examples of this willingness to try new things is the experimental house by Alvar Aalto.

The experimental house provided a testbed for using different kinds of materials in different ways, allowing for the observation of their characteristics and application opportunities. The lessons learned from this experimental house eventually found their way into Aalto's designs and were as such exported around the world in the approximately 200 buildings he realized.

Now, roughly 70 years later we are faced with a building sector that is plagued by low productivity, an increasing lack of skilled personnel, an increasingly volatile resource supply chain, a more than significant contribution to the world's carbon emissions (35%!), and last but not least, an enormous amount of waste generation.

We need to start to experiment again! We need our 2023 version of Aalto's experimental house, that will show us how we can work with the materials of our future. More than just experimenting and applying with these future materials, we also need to investigate how to design with them, how to connect them (both physically and digitally), and how they influence our living environment. Let's aim to spread the results of our experiments around the world, allowing Finland to set the international standard once again.

Figure 5: Alvar Aalto's experimental house in Muuratsalo, Finland (source: Alvar Aalto Säätiö)

8. Concluding remarks & Recommendations

This research has provided insight into the theoretical state of art of CE in the built environment through a literature study, as well as into the practical state of art through an opportunity map. Even though the opportunity map includes a variety of examples from practice, for certain categories the sample size is limited and should be expanded in further research. Another word of caution is that the opportunity map provides a snapshot of the current situation and will age if it is not updated regularly.

Notwithstanding these limitations this report was able to cover the current state of art and its (lacking) developments. From this, it can be seen that there have been substantial efforts in both theory and practice to advance the adoption of CE in the built environment. At the same time, this has also revealed several areas where (further) research is necessary.

This has led to a proposal for a real-life experimental house with certain guidelines and areas of interest based upon the literature review and opportunity map. Even if some verification has taken place in writing this report, further development that will lead to the actual realization of the experimental house should consult and continuously validate the approach presented in this report with the stakeholders involved in said realization.

From a research point of view, this report showed the compliance of technical DfD buildings with the circular economy. If care is given to evaluate the compliance of those cases with CE principles and strategies, this might provide future research with an extended body of case-studies along with relevant lessons learned for the realization of the circular economy in the built environment.

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Appendices

Appendix A - Realized New-Built Projects with a Circular point of view

The primary input for the table has come from Moos Heunicke & Vejlgaard (2021) and Nußholz et al. (2023). The input has (1) been qualitatively reviewed and the author has (2) added any missing data in columns E-J. All data added and/or modified by the author after review are marked in *Italics*. The following needs to be noted regarding the data in specific columns of the table:

- Column C: The terms ‘StructureMA’, ‘StructureSY’, ‘Flexibility’, ‘Principle 1’, and ‘Principle 2’ originate from Moos Heunicke & Vejlgaard (2021), and their explanations can be found there
- Column E: Built with CE principles in mind means the building itself, its design or construction is advertised as being circular by its stakeholders
- Column F: Yes/No-criterion based on the data gathered in columns G-J
- Column G: ‘CE Categories of Principles applied’ refers to the explanations given in Nußholz et al. (p.2, 2023)
- Column H: ‘Circular building strategies applied’ refers to the strategies presented for new built projects in Nußholz et al. (p.2, 2023)
- Column I: The ‘Circular in/out/both?’ assesses whether the examined project takes into account the materials and products going IN the project, the materials and products going OUT the project after its lifetime, or whether BOTH are taken into account.
- Column J: ‘Has building been dismantled / recycled / demolished?’ examined whether the assessed project is still operational and in place. Satellite-view and/or Streetview (when available) in Google Maps was used to ascertain whether the reference project is still in place (care was taken to check the date of the satellite images)

The following needs to be noted regarding data-processing of the two primary sources:

1. Moos Heunicke & Vejlgaard (2021) > The primary source provides examples of flexible and Design-for-Disassembly (DfD) projects.

   a. Only projects exhibiting technical flexibility (Durmisevic, 2006), are included in this study. The projects exhibiting spatial flexibility are not considered under the presumption that these cannot be dismantled at the end of their lifetime. Given that these projects were not originally built with sustainable criteria in mind, also the ‘IN’-side of these projects is not expected to yield relevance when it comes to circularity, further limiting their usefulness here.
   b. 5 cases (Het Schetsblock, New-WestResidence, MIMA House, Centre Georges Pompidou, and Sainsbury Centre for Visual Arts) were additionally excluded as the author deemed them to be spatially flexible, but not technically flexible.
   c. Only European examples are included here (to enhance comparability and validity of solutions between sources).
   d. For references where the link to the source was broken, first the existence of an alternative link was investigated. Alternative links have been written in *italics*. If an alternative link could not be found, the reference was removed from the list (this was done for 2 cases; D10, and Adjustable Pallet Racking).
   e. Information in description written by the original authors has been used as a basis to determine the CE strategies and Circular Building Strategies used. Only in case this was not clear enough, further information was sourced through the provided link.

2. Nußholz et al. (2023) > Academic new-built examples not taken into account, as access to references was restricted and/or objects that are described are not identifiable enough.

   a. 1 overlapping case (Upcycle house) was found between Moos Heunicke & Vejlgaard (2021) and Nußholz et al. (2023), this case has only been listed once.
   b. Buildings that were taken apart and reconstructed elsewhere 1:1 are not on this list, as they are not new built, but rebuilt (even though circular). This concerned 1 case; Segro Warehouse.
   c. 1 case (The Dutch Mountains) does not concern a realized, real-world project and was therefore removed from the list.
   d. For 1 case (HAUT), it was mentioned in the original source to be DfD-compliant, further examination however proves this is not the case. The author has adapted the applicable CE strategies accordingly.

#	Project Name	Data	Description	Built with CE principles in mind (Y/N)	Adheres to CE Principles or has followed circular building strategies (Y/N)	CE Categories of Principles applied	Circular building strategies applied	Circular in/out/both?	Has building been dismantled / recycled / demolished?	Source
1	Skaio	Year: 2019 Type: Residential Location: Heilbronn, DE Architect: Kaden + Lager Developer: n.a. Size: 5,685 m2 StructureMA: Timber StructureSY: Column/Slab Flexibility: Technical Principle 1: Replaceability Principle 2: Reconfiguring	Skaio has Cradle to Cradle inspired material solutions, which make the building 100 percent recyclable. In case of reconstruction, the elements can be separated from each other by type and reassembled at the desired location. *"Skaio Wooden Apartment Building / Kaden + Lager." Retrieved 11.07.2023, from: https://www.archdaily.com/949490/skaio-wooden-apartment-building-kaden-plus-lager*	*No*	*Yes*	*Closing, Regenerating*	*Design for reversibility* *Design for reuse* *Materials with low embodied carbon* *Renewable and non-toxic materials* *Avoidance of carbon intensive components and structural elements* *Intensive use of space*	*Both*	*No*	Moos Heunicke & Vejlgaard, 2021
2	Universal Design Quarter	Year: 2017 Type: Residential Location: Hamburg, DE Architect: Sauerbruch Hutton Developer: HOWOGE Size: 13,510 m2 StructureMA: Hybrid StructureSY: Box-construction Flexibility: Technical Principle 1: Replaceability Principle 2: Reconfiguring	The purpose and the functional layout of the student hall of residence are clearly expressed in the exterior of the Universal Design Quarter. The ground floor structure and the three service cores are in conventional reinforced concrete construction with an additional outer shell of exposed concrete. Simply put, the ground floor structure is a kind of concrete table, on which the 371 residential wooden modules are stacked for five or six floors. The apartments each have a floor area of 20 m² and they are completely prefabricated from solid wood, including their fixtures. ArchDaily. "Universal Design Quarter in Hamburg / Sauerbruch Hutton," Retrieved 11.07.2023, from: https://www.archdaily.com/944258/universal-design-quarterin-hamburg-sauerbruch-hutton	*No*	*Yes*	*Regenerating*	*Design for reversibility* *Design for reuse* *Materials with low embodied carbon* *Renewable and non-toxic materials* *Avoidance of carbon intensive components and structural elements* *Resource efficiency in construction* *Waste prevention/reduction during construction*	*Both*	*No*	Moos Heunicke & Vejlgaard, 2021
3	Flexline	Year: 2002 Type: Residential Location: Hegelo, NL Architect: n.a. Developer: n.a. Size: n.a. StructureMA: Hybrid StructureSY: Box-construction Flexibility: Technical Principle 1: Reconfiguring Principle 2: Replaceability	Flexline is the development of an industrially manufactured construction system for social housing, which allows for a great flexibility in the floor plans. An apartment consists of 4 prefabricated modules. On site, the elements are connected, and installations are added. The modular construction enables an apartment to be expanded at any time. Also, it is possible to reuse a module off-site, or recycle its materials. "Endbericht_1121_recyclingfaehig_konstruieren.Pdf." Retrieved 11.07.2023, from: https://www.nachhaltigwirtschaften.at/resources/hdz_pdf/endbericht_1121_recyclingfaehig_konstruieren.pdf	*No*	*Yes*	*Closing*	*Design for reuse* *Resource efficiency in construction* *Waste prevention/reduction during construction*	*Out*	*Unknown*	Moos Heunicke & Vejlgaard, 2021

#	Project Name	Data	Description	Built with CE principles in mind (Y/N)	Adheres to CE Principles or has followed circular building strategies (Y/N)	CE Categories of Principles applied	Circular building strategies applied	Circular in/out/both?	Has building been dismantled / recycled / demolished?	Source
4	Modular Apartments	Year: 2010 Type: Residential Location: Toulouse, FR Architect: PPA Architecture Developer: n.a. Size: 1,136 m2 StructureMA: Timber StructureSY: Box-construction Flexibility: Technical Principle 1: Reconfiguring Principle 2: Replaceability	The modular apartments are made of a prefabricated stacked construction. The amount of prefabrication has meant a short building time of about two months from the delivery of the first modules to the completion of the outer shell. Against the background of significant urban densification, the architects' real achievement lies in the creation of well-proportioned urban spaces by means of a repetitive building system. *"50 Modular Timber Apartments / PPA architectures." Retrieved 11.07.2023, from: https://www.archdaily.com/787698/50-modular-timber-apartments-ppa-architectures*	*No*	*Yes*	*Regenerating*	*Materials with low embodied carbon* *Renewable and non-toxic materials* *Avoidance of carbon intensive components and structural elements* *Resource efficiency in construction* *Waste prevention/reduction during construction*	*Both*	*No*	Moos Heunicke & Vejlgaard, 2021
5	Frankie & Johnny	Year: 2018 Type: Residential Location: Berlin, DE Architect: Holzer Kobler Architecturen Developer: Size: n.a. StructureMA: Steel StructureSY: Box-construction Flexibility: Technical Principle 1: Reconfiguring Principle 2: Replaceability	The Frankie & Johnny student dormitory consists of stacked containers. It was completed in a short time and is an answer to the acute housing need in Berlin. Modular construction and the recycling of building materials are demonstrated. The containers are stacked on concrete strip footings with locally reinforced foundations. At the nodes, the High Cubes are connected to each other. Sound-absorbing polymer bearings are used to prevent structure-borne noise transmission between the containers. The joints between the containers in the facades are closed windproof. Transverse bracing of the two ends of open containers is provided by a reinforced frame structure. The container rows are each closed at the top with a completely sealed roof. The pergola and staircase structure are an independent structure separated from the containers. "frankie and johnny." Retrieved 11.07.2023, from: https://bauforumstahl.de/bauprojekte/frankie-johnny	*No*	*Yes*	*Slowing, Closing*	*Secondary materials and components* *Reuse of (carbon-intensive) components and structural materials*	*In*	*Yes* *(Due to technical malfunctions, materials not reused!)*	Moos Heunicke & Vejlgaard, 2021
6	CPH village	Year: 2018 Type: Residential Location: Copenhagen, DK Architect: Arcgency, Vandkunsten Developer: n.a. Size: n.a. StructureMA: Steel StructureSY: Box-construction Flexibility: Technical Principle 1: Separation Principle 2: Accessibility	CPH Village is a company on a mission to solve the student housing crisis by building sustainable and modular villages with value driven communities. At CPH Village the entire lifecycle of the building is in focus. Repurposed containers are adapted into housing using the principles of Design for Disassembly - a method that enables the buildings to be easily taken apart - moved - and reassembled. By doing so the village can be relocated at a new site when the current area is ready for permanent development. The approach incites use of quality materials - as it is only the site that is temporary - the building can have a long life and after end of use all materials can be reused or recycled. "Arcgency - CPH VILLAGE - REFSHALEØEN." Retrieved 11.07.2023, from: https://arcgency.com/cph-village	*No*	*Yes*	*Slowing, Closing*	*Design for durability and long-life* *Design for reversibility* *Design for reuse* *Secondary materials and components* *Reuse of (carbon-intensive) components and structural materials*	*Both*	*No*	Moos Heunicke & Vejlgaard, 2021

#	Project Name	Data	Description	Built with CE principles in mind (Y/N)	Adheres to CE Principles or has followed circular building strategies (Y/N)	CE Categories of Principles applied	Circular building strategies applied	Circular in/out/both?	Has building been dismantled / recycled / demolished?	Source
7	Cala Domus	Year: 2002 Type: Residential Location: Newhall, UK Architect: PCKO Architects Developer: n.a. Size: n.a. StructureMA: Hybrid StructureSY: Walls/Slab Flexibility: Technical Principle 1: Reconfiguring Principle 2: Accessibility	In the PCKO's houses in Newhall (UK) the problem of the servicing has be resolved by the concept of a "Living Wall". The project consists of 74 units (apartments, houses, workspaces) which are all equipped with a central structure called "Living Wall". In the central zone of the house there is a dedicated space in which are located all the technical systems both horizontal and vertical: pipes, wiring but also space for recycling and garbage are all condensed in this strip that runs through all the house. The kitchens and barrooms are also attached or extend into this wall. The zone has been provided with internal and external access so that when it comes the time for a renewal, a refurbishment or simply a changing in the house layout, the technical systems can be changed, replaced or moved without having to demolish parts of the house. The living wall is also adaptable for additional future uses as technologies change over time. In fact, the Living Walls act like a fuse: it adsorbs most of the complex technological changes that are required to have an adaptation of the interior layout. *"CALA Homes, New Hall, Harlow Architect: PCKO Architects" Retrieved 11.07.2023, from: https://www.alamy.com/cala-homes-new-hall-harlow-architect-pcko-architects-image398315913.html*	*No*	*Yes*	*Slowing*	*Design for durability and long-life* *Design for easy maintenance and repair* *Maintenance and repair with minimum resources*	*Out*	*Unknown*	Moos Heunicke & Vejlgaard, 2021
8	De Kersentuin	Year: 2003 Type: Residential Location: Utrecht, NL Architect: De Kersentuin resident´s association, Kristinsson Developer: n.a. Size: StructureMA: Timber StructureSY: Column/Beam Flexibility: Technical Principle 1: Reconfiguring Principle 2: Accessibility	De Kersentuin (The Cherry Orchard) began as a resident led initiative to develop a sustainable housing district in Utrecht, Netherlands. The timber framed homes are part of the IFD (Industrial, Flexible, Demountable) movement in the Netherlands. The initial residents could choose from a variety of layouts including three locations for the stairs, while the 6m spans, lightweight partition walls, finishes, and equipment systems allow for subsequent versatility during use. The versatility is suited to adapt the homes for the disabled and elderly practical for lifetime adaptations as well. The homes are extendable in the back with additional strip foundations in place and the rear façades being demountable. Connections are made removable and reusable for refitting and disassembly and are documented with a demolition plan. Adaptable futures. "Case Studies," Retrieved 11.07.2023, from: http://adaptablefutures.com/our-work/case-studies/	*No*	*Yes*	*Closing*	*Design Optimization* *Design for durability and long-life* *Design for reversibility* *Materials with low embodied carbon* *Avoidance of (carbon-intensive) components and structural elements*	*Out*	*No*	Moos Heunicke & Vejlgaard, 2021
9	Il rigo quarter	Year: 1982 Type: Residential Location: Perugia, IT Architect: RPBW Developer: Size: 20,438 m2 StructureMA: Steel StructureSY: Column/Beam Flexibility: Technical Principle 1: Reconfiguring Principle 2: Accessibility	This project developed the idea of 'flexible' architecture by creating houses that could be reshaped and adapted according to their inhabitants' needs. Each house is six meters high and six meters wide, with floor space ranging from 50 to 120 m2. The internal volume of each house can be increased by moving the glazed front wall outwards, and at first floor level by inserting a new floor into the double height living space, supported on lightweight metal trusses. "RPBW - Il Rigo Quarter." Retrieved 11.07.2023, from: http://www.rpbw.com/project/il-rigo-quarter	*No*	*No*	-	-	-	*No*	Moos Heunicke & Vejlgaard, 2021

#	Project Name	Data	Description	Built with CE principles in mind (Y/N)	Adheres to CE Principles or has followed circular building strategies (Y/N)	CE Categories of Principles applied	Circular building strategies applied	Circular in/out/both?	Has building been dismantled / recycled / demolished?	Source
10	CiWoCo	Year: 2019 Type: Residential Location: Amsterdam, NL Architect: GAAGA Developer: Cooperatie BSH 20E, Vinkbouw Nieuwkoop, Bestcon, OntwerpJeWoning, Van Rossum, Hiensch, moBius consult, NIBE experts in sustainability, 3B Building support Size: 1,500 m2 StructureMA: Concrete StructureSY: Column/Slab Flexibility: Technical Principle 1: Reconfiguring Principle 2: Accessibility	GAAGA designed an exceptionally sustainable, adaptive, and almost completely demountable building that also adapts to the living-work wishes of the residents in the future. The future residents had an influence on the design process in this project, a consequence of the approach in the form of a construction group. The building is adaptive and adapts to the use that the residents make of it. As a result, it can move with future changes, which ensures a future-proof building. Thanks to their own access, the workspaces are, for example, emphatically suitable for multiple functions. Another design choice that makes the building adaptive is the open living space with column structure and without load-bearing partitions between the houses. This makes it possible to merge homes relatively easily in the future. An example of demountable construction is the prefab concrete shell. Normally, the pipework is collapsed into the floors. The water supply, electricity and sewerage are included in retention walls and suspended ceilings. Due to the separation of construction and installations and the demountable constructive connections, the hull is completely demountable. Due to the lack of collapsed installations, the bearing floor is also considerably thinner, which saves material. In addition to building in a way that you can reuse the materials, circular construction is also about reusing materials from other structures. The building considers the concept of urban mining and interprets the building as a storage place for raw materials that you want to mine at the end of its useful life for reuse. *"Gaaga | CiWoCo Amsterdam." Retrieved 11.07.2023, from: https://gaaga.nl/CiWoCo-Amsterdam*	*Yes*	*Yes*	*Narrowing, Closing*	*Design optimization* *Dematerialisation and lightweight construction* *Design for easy maintenance and repair* *Design for reversibility* *Secondary materials and components* *Intensive use of space*	*Both*	*No*	Moos Heunicke & Vejlgaard, 2021
11	Upcyle House	Year: 2013 Type: Residential Location: Nyborg, DK Architect: Lendager Arkitekter Developer: n.a. Size: 129 m2 StructureMA: Steel StructureSY: Box-construction Flexibility: Technical Principle 1: Replaceability Principle 2: Separation	Upcycle House is an experimental project, aimed at exposing potential carbon-emission reductions through circular design. The reduction has been 86% compared to a benchmark house. The loadbearing structure consists of two prefabricated shipping containers, ArchDaily. "Upcycle House / Lendager Arkitekter," Retrieved 11.07.2023, from: https://www.archdaily.com/458245/upcycle-houselendager-arkitekter	*Yes*	*Yes*	*Slowing, Closing*	*Secondary materials and components* *Reuse of (carbon-intensive) components and structural elements*	*Both*	*No*	Moos Heunicke & Vejlgaard, 2021, Nußholz et al. (2023)

#	Project Name	Data	Description	Built with CE principles in mind (Y/N)	Adheres to CE Principles or has followed circular building strategies (Y/N)	CE Categories of Principles applied	Circular building strategies applied	Circular in/out/both?	Has building been dismantled / recycled / demolished?	Source
12	Casco Façade	Year: 2003 Type: Residential Location: Oegstgeest, NL Architect: Reiner Witteveen Developer: N7A Size: 50 m2 StructureMA: Steel StructureSY: Column/Beam Flexibility: Technical Principle 1: Replaceability Principle 2: Reconfiguring	Casco Façade is an affordable detached house with freely divisible floor plans and facades. The main loadbearing structure - steel tubular profiles outside the facade - is at the basis of free subdivision of the facades and of 50 m2 of floor space, divided over two storeys. *"Casco Facade." Retrieved 11.07.2023, from: https://architectenweb.nl/projecten/project.aspx?ID=2976*	*No*	*Yes*	*Closing*	*Dematerialisation and lightweight construction* *Design for reversibility* *Resource efficiency in construction* *Waste prevention/reduction during construction*	*Out*	*Unknown*	Moos Heunicke & Vejlgaard, 2021
13	Recycling House	Year: 2019 Type: Residential Location: Hannover, DE Architect: Cityförster Architecture + Urbanism Developer: n.a. Size: 285 m2 StructureMA: Timber StructureSY: Walls/Slab Flexibility: Technical Principle 1: Separation Principle 2: Accessibility	The recycling house is an experimental residential building in the Hanover district of Kronsberg. It is a prototype that tests the possibilities and potentials of various types of recycling in the real laboratory and shows a cycle-oriented and resource-saving planning approach. Particularly important is a recycling-fair design that allows use and disassembly of the components without loss of quality or a sorted separation of the materials after the end of life. *"Recyclinghaus." Retrieved 11.07.2023, from: https://www.cityfoerster.net/projects/recyclinghaus-218-2.html*	*No*	*Yes*	*Slowing, Closing*	*Design for reversibility* *Design for reuse* *Renewable and non-toxic materials* *Secondary materials and components* *Avoidance of (carbon-intensive) components and structural elements*	*Both*	*No*	Moos Heunicke & Vejlgaard, 2021
14	Cork House	Year: 2019 Type: Residential Location: Eton, UK Architect: MPH Architects, UCL the Bartlett Developer: n.a. Size: 75 m2 StructureMA: Cork StructureSY: Walls/Slab Flexibility: Technical Principle 1: Accessibility Principle 2: Separation	The Cork House is an entirely cork construction, with solid structural cork walls and roof. It has an exceptionally low carbon footprint during its whole life cycle. The house is designed for disassembly and can be constructed by hand. "Cork House." Retrieved 11.07.2023, from: https://www.architecture.com/awards-and-competitionslanding-page/awards/riba-regional-awards/riba-southaward-winners/2019/cork-house	*No*	*Yes*	*Closing, Regenerating*	*Dematerialization and lightweight construction* *Design for reversibility* *Materials with low embodied carbon* *Renewable and non-toxic materials* *Avoidance of (carbon-intensive) components and structural elements* *Resource efficiency in construction* *Waste prevention/reduction during construction* *Low-carbon construction equipment*	*Both*	*No*	Moos Heunicke & Vejlgaard, 2021

#	Project Name	Data	Description	Built with CE principles in mind (Y/N)	Adheres to CE Principles or has followed circular building strategies (Y/N)	CE Categories of Principles applied	Circular building strategies applied	Circular in/out/both?	Has building been dismantled / recycled / demolished?	Source
							Maintenance and repair with minimum resources			
15	Segal Close	Year: 1980 Type: Residential Location: London, UK Architect: Walter Segal Developer: Walter Segal Size: 100 m2 StructureMA: Timber StructureSY: Column/Beam Flexibility: Technical Principle 1: Separation Principle 2: Replaceability	The Segal Method was developed by architect Walter Segal to provide inexpensive, temporary accommodation for his family while renovating the main house. It evolved into a simple method focusing on disassembly and avoiding loss in material value. The designed relies on standardised construction materials, used in a modular layout. Connections are bolted, to ease for disassembly. The Segal Close is a house built after the Segal Method by residents. *InFutUReWood. "The Segal Method: Designing for Disassembly," Retrieved 11.07.2023, from: https://www.infuturewood.info/the-segal-method-designing-for-disassembly/#:~:text=Segal%27s%20preoccupation%20during%20the%20design,used%20in%20a%20modular%20layout.*	*No*	*Yes*	*Closing, Regenerating*	*Dematerialisation and lightweight construction* *Design for reversibility* *Avoidance of (carbon-intensive) components and structural elements* *Resource efficiency in construction*	*Out*	*Unknown*	Moos Heunicke & Vejlgaard, 2021
16	R 128	Year: 2000 Type: Residential Location: Stuttgart, DE Architect: Werner Sobek Developer: Size: 250 m2 StructureMA: Steel StructureSY: Column/Beam Flexibility: Technical Principle 1: Accessibility Principle 2: Replaceability	This four-storey building R 128 is completely recyclable, produces no emissions and is self-sufficient in terms of heating energy requirement. Its design is modular. Because of its assembly by means of mortice-and-tenon joints and bolted joints, it cannot only be assembled and dismantled easily but is also completely recyclable. The electrical energy required for the energy concept and control engineering is produced by solar cells. *Werner Sobek. "R128," Retrieved 11.07.2023, from: https://www.wernersobek.com/projects/r128/*	*No*	*Yes*	*Closing*	*Design for reversibility* *Improve operational efficiency*	*Out*	*No*	Moos Heunicke & Vejlgaard, 2021
17	KODA	Year: 2015 Type: Residential Location: Harkujärve, EE Architect: Kodasema Developer: n.a. Size: 26 m2 StructureMA: Hybrid StructureSY: Walls/Slab Flexibility: Technical Principle 1: Accessibility Principle 2: Separation	No stakes to pull up or new foundation to pour for owners of this prefabricated dwelling, an open-plan home designed to be built, taken apart, moved and reconstructed on demand. Its factory-made components can be shipped between sites, assembled in less then eight hours and taken apart just as quickly. Disassemble, reassemble — it's that easy. The so-called KODA features a lofted bedroom, open-plan living space and requires only a 270-square-foot site for deployment. In short: their solution is efficient, economic, and ecological, optimizing use of time and materials while allowing for flexibility. "Its clever design provides the inspiration to make best use of every square inch of space and envisage how the built-in components, even the walls, can be adjusted to meet their purpose most effectively. *"KODA Loft," Retrieved 11.07.2023, from: https://kodasema.com/en/koda-loft/*	*No*	*Yes*	*Slowing, Regenerating*	*Design Optimization* *Dematerialisation and lightweight construction* *Design for reuse* *Materials with low embodied carbon* *Resource efficiency in construction* *Waste prevention/reduction during construction* *Low-carbon construction equipment* *Intensive use of space*	*Both*	*Unknown*	Moos Heunicke & Vejlgaard, 2021

#	Project Name	Data	Description	Built with CE principles in mind (Y/N)	Adheres to CE Principles or has followed circular building strategies (Y/N)	CE Categories of Principles applied	Circular building strategies applied	Circular in/out/both?	Has building been dismantled / recycled / demolished?	Source
18	Demountable houses	Year: 1944 Type: Residential Location: Lorraine and Franche-Comté, FR Architect: Jean Prouvé Developer: n.a. Size: 54 m2 StructureMA: Steel StructureSY: Column/Beam Flexibility: Technical Principle 1: Separation Principle 2: Accessibility	Immediately after the war, Prouvé designed temporary houses based on his axial portal frame structure. He received a contract from the Ministry of Reconstruction and Town Planning for 800 temporary houses (later changed to 400) for displaced people in Lorraine and Franche-Comté. House dimensions were set at 6 x 9 meters. Built from light, prefabricated components of metal and wood, these temporary houses were designed for rapid assembly on the sites of destroyed homes. Because of strict post-war quotas, the use of steel was limited to the load bearing bent steel portal frame, into which were inserted simple, standardized, 1-meter wide panels for the exterior walls, doors and windows. The house could be partitioned into three rooms and was immediately habitable. These temporary houses could be demounted and moved elsewhere if needed. About 20 of these houses have survived. *"Jean-Prouvé-Demountable-Houses-Converted.Pdf." Retrieved 11.07.2023, from: https://lynceans.org/wp-content/uploads/2020/06/Jean-Prouv%C3%A9-demountable-houses-converted.pdf*	*No*	*Yes*	*Slowing*	*Design Optimization* *Dematerialisation and lightweight construction* *Design for reuse* *Resource efficiency in construction* *Waste prevention/reduction during construction* *Low-carbon construction equipment*	*Out*	*Unknown*	Moos Heunicke & Vejlgaard, 2021
19	Métropole Standard House	Year: 1949 Type: Residential Location: FR Architect: Jean Prouvé Developer: n.a. Size: 64-96 m2 StructureMA: Steel StructureSY: Column/Beam Flexibility: Technical Principle 1: Separation Principle 2: Accessibility	Prouvé developed the design of demountable houses and, in 1949, produced the Métropole House, which was the prototype for a house intended for large scale production, primarily for French overseas colonies. The house was entirely prefabricated and would be partially assembly in the factory prior to shipment. The French government only ordered 12 Métropole houses. Prouvé's firm, Ateliers Jean Prouvé in Maxéville, produced 25 of these units, with commercial customers taking the units not delivered to the government. Ten Métropole Standard house units were erected on masonry foundations on uneven ground in a small residential development in the Meudon suburbs of Paris. This small development, known as Cité "Sans souci," also includes four of Prouve's Maison coques-style "Shell" houses. *"Jean-Prouvé-Demountable-Houses-Converted.Pdf." Retrieved 11.07.2023, from: https://lynceans.org/wp-content/uploads/2020/06/Jean-Prouv%C3%A9-demountable-houses-converted.pdf*	*No*	*Yes*	*Slowing*	*Design Optimization* *Dematerialization and lightweight construction* *Design for reuse* *Resource efficiency in construction* *Waste prevention/reduction during construction* *Low-carbon construction equipment*	*Out*	*No*	Moos Heunicke & Vejlgaard, 2021

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20	Pop-Up House	Year: 2014 Type: Residential Location: Aix-en-Provence, FR Architect: Multipod Studio Developer: n.a. Size: 150 m2 StructureMA: Timber StructureSY: Walls/Slab Flexibility: Technical Principle 1: Replaceability Principle 2: Separation	Four days and a wireless screwdriver is all that is needed to build a Pop-Up House. The structure, compiled of insulating blocks and wooden panels, delivers affordable thermal insulation. Determined to develop solutions, Multipod Studio have patented a unique approach to passive construction that delivers outstanding thermal insulation at an affordable cost. No special tools required, the house is assembled using lightweight and recyclable materials for quick installation. ArchDaily. "Pop-Up House / Multipod Studio," Retrieved 11.07.2023, from: https://www.archdaily.com/486587/pop-up-housemultipod-studio	*No*	*Yes*	*Narrowing*	*Dematerialization and lightweight construction* *Design for reversibility* *Avoidance of (carbon-intensive) components and structural elements* *Resource efficiency in construction* *Waste prevention/reduction during construction* *Low-carbon construction equipment*	*Out*	*No*	Moos Heunicke & Vejlgaard, 2021
21	Project XX	Year: 1999 Type: Office Location: Delft, NL Architect: XX Architecten Developer: n.a. Size: 2,000 m2 StructureMA: Timber StructureSY: Column/Beam Flexibility: Technical Principle 1: Reconfiguring Principle 2: Separation	'XX' in the name Project XX stands for the Roman number 20, as this ecological building was designed to function for twenty years. After that time the buildings' sustainable materials would have reached the end of their lifespan and theoretically the building would perish slowly without burdening the environment. The construction of XX Architecten shows an exemplary separation of shell construction and finishing. The load-bearing structures and the filling elements are demountable and designed so that during assembly and disassembly damage to the construction parts can be avoided. All Constructions are demountable. Furthermore, the interior fittings (non-load-bearing interior walls, floor superstructures, etc.) are separated from the supporting structures. During assembly and disassembly, the load-bearing structural parts are therefore not damaged. *"Office Building C`XX," Retrieved 11.07.2023, from: http://www.architectureguide.nl/project/list_projects_of_architect/arc_id/1942/prj_id/1830*	*No*	*Yes*	*Closing, Regenerating*	*Dematerialization and lightweight construction* *Design for reversibility* *Design for reuse* *Materials with low embodied carbon* *Avoidance of (carbon-intensive) components and structural elements*	*Out*	*No*	Moos Heunicke & Vejlgaard, 2021
22	Triodos Bank	Year: 2019 Type: Office Location: Driebergen-Rijsenburg, NL Architect: RAU Architects Developer: n.a. Size: 12,994 m2 StructureMA: Timber StructureSY: Column/Slab Flexibility: Technical Principle 1: Separation Principle 2: Reconfiguring	This office building serves as a temporary material bank, and the CO2 footprint is minimal. The origin and planned re-use of all products, components, and materials are carefully documented to be able to easily offer them new usage in the future. The building is screwed together with 165,312 screws. This means that whenever dismantling the building, the circular potential can be activated 100% without loss of value of materials, components, and products. ArchDaily. "Triodos Bank / RAU Architects," Retrieved 11.07.2023, from: https://www.archdaily.com/926357/triodos-bank-rauarchitects	*Yes*	*Yes*	*Slowing, Closing, Regenerating*	*Design for reversibility* *Design for reuse* *Materials with low embodied carbon* *Renewable and non-toxic materials* *Avoidance of (carbon-intensive) components and structural elements*	*Both*	*No*	Moos Heunicke & Vejlgaard, 2021

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23	Kreislaufhaus	Year: 2017 Type: Office Location: Essen, DE Architect: n.a. Developer: n.a. Size 9,400 m2 StructureMA: Concrete StructureSY: Walls/Slab Flexibility: Technical Principle 1: Separation Principle 2: Reconfiguring	The administration building of the RAG Foundation and RAG AG represents all aspects of a sustainable building for the future. It shows how the goals of sustainable building can be considered in all areas of planning, construction and building operation. Even the choice of building materials considers not only all aspects of environmental impact during manufacture, processing, and deconstruction, but also the effects on indoor air and the comfort of the users. The project is also part of a research project to investigate the future use of the building as a raw material storage facility. Material registers document the location, quantities and quality of the building materials used. *"Kreislaufhaus", Retrieved 11.07.2023, from: https://www.kadawittfeldarchitektur.de/projekt/rag-stiftung-und-rag-ag-zollverein/*	*No*	*Yes*	*Slowing, Closing*	*Design for reuse* *Materials with low embodied carbon* *Renewable and non-toxic materials*	*Both*	*No*	Moos Heunicke & Vejlgaard, 2021
24	Braunstein Taphouse	Year: 2020 Type: Culture Location: Køge, DK Architect: ADEPT Developer: n.a. Size: 1,000 m2 StructureMA: Timber StructureSY: Column/Beam Flexibility: Technical Principle 1: Replaceability Principle 2: Separation	The Braunstein Taphouse rests on a stretch of a municipality owned harbor quay that is considered a potential part of the city's climate adaption strategy. To integrate this possible temporary lifespan in its architecture, the Taphouse is 'designed for disassembly' to make recycling of building components a realistic option if the building cannot stay – either by re-completing the entire building at a different location or by using the materials in other projects. The Braunstein Taphouse is constructed from few and sustainable building materials that, as far as possible, are not mixed. This has reduced the volume of waste considerably compared to similar constructions. The structure is based on simple tectonic principles and is completed with mechanical joints only. *The Braunstein Taphouse - ADEPT." Retrieved 11.07.2023, from: https://adept.dk/project/the-braunstein-taphouse*	*No*	*Yes*	*Narrowing, Slowing, Closing*	*Dematerialization and lightweight construction* *Design for reversibility* *Design for reuse* *Waste prevention/reduction during construction*	*Both*	*No*	Moos Heunicke & Vejlgaard, 2021
25	Run Shopping Center	Year: 2001 Type: Commercial Location: Wormerveer, NL Architect: n.a. Developer: n.a. Size: 41,000 m2 StructureMA: Concrete StructureSY: Walls/Slab Flexibility: Technical Principle 1: Separation Principle 2: Accessibility	The shopping centre with an area of 41.000 m2 is made of prefabricated reinforced concrete elements which are connected on site and can be dismantled. Through standardized façade and roof elements, it is possible to quickly and efficiently repair or replace parts. The building is designed in such a way that changes of use are possible at any time: Through the opening the roof areas, even entire staircases can be moved with the help of a crane, the inner walls are non-load-bearing and are therefore just as easily adapted to new uses to be adjusted. "Endbericht_1121_recyclingfaehig_konstruieren.Pdf." Retrieved 11.07.2023, from: https://www.nachhaltigwirtschaften.at/resources/hdz_pdf/endbericht_1121_recyclingfaehig_konstruieren.pdf	*No*	*Yes*	*Slowing*	*Design for easy maintenance and repair* *Design for reversibility* *Intensive use of space*	*Out*	*No*	Moos Heunicke & Vejlgaard, 2021

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26	Circl	Year: 2017 Type: Mixed-use Location: Amsterdam, NL Architect: De Architekten Cie Developer: n.a. Size: 9,000 m2 StructureMA: Timber StructureSY: Column/Slab Flexibility; Technical Principle 1; Replaceability Principle 2; Reconfiguring	The new 'Circl' pavilion is unique in the Netherlands: the first constructed practical example of sustainable and circular designs. Project architect Hans Hammink: 'We used a design strategy in which waste is avoided as far as possible. This starts with the reuse of materials that have had a previous life. As far as possible, parts of the structure have been put together in such a way that in the event of a replacement or demolition, they can be reused. Various parts, such as lifts and lighting, have been supplied via a lease construction and remain the property of the supplier. All materials, components and parts that make up the building have been recorded in a 'digital twin'; the building passport is named LLMNT. Architizer. "Circl by de Architekten Cie.," Retrieved 11.07.2023, from: https://architizer.com/projects/circl/	*Yes*	*Yes*	*Slowing, Closing*	*Design for reversibility* *Design for reuse* *Secondary materials and components* *Reuse of (carbon-intensive) components and structural elements*	*Both*	*No*	Moos Heunicke & Vejlgaard, 2021
27	Green Solution House	Year; 2015 Type; Leisure Location; Bornholm, DK Architect 3XN / GXN Developer: n.a. Size: 4,500 m2 StructureMA: Hybrid StructureSY: Hybrid Flexibility: Technical Principle 1: Replaceability Principle 2: Separation	At Green Solution House circular sustainability is explored. The architects wanted the best building possible for the times, one that would contribute to the health of both people and nature. Achieving this meant exploring innovative systems and materials plus developing strategies for how to live up to our ambitions. The exploration is rooted in three sustainability strategies and constantly informed by local conditions and pragmatic use of resources. Green Solution House is certified to the standards of the German Sustainable Building Council (DGNB). The design is based on the criteria of the Active House vision and inspired by the Cradle to Cradle life cycle concept. "GXN Green Solution House." Retrieved 11.07.2023, from: https://gxn.3xn.com/project/green-solution-house	*Yes*	*Yes*	*Slowing, Closing, Regenerating*	*Dematerialization and lightweight construction* *Design for reversibility* *Secondary materials and components*	*Both*	*No*	Moos Heunicke & Vejlgaard, 2021
28	Freitag Flagship Store	Year: 2006 Type: Commercial Location: Zürich, CH Architect: Spillmann echsle Developer: Size: 278 m2 StructureMA: Steel StructureSY: Box-construction Flexibility: Technical Principle 1: Accessibility Principle 2: Separation	While the base contains a retail store, the tower figures as a landmark in the midst of the international traffic axes of railway and individual traffic. The seventeen used overseas cargo containers were specially selected in Hamburg and brought to Zurich by railway, where they were stacked and mounted in a very authentic manner. The stacking of the units is based on their original design logic: only connecting elements from the shipping industry are used, thus ensuring simple dismantling. By detaching longitudinal walls and ceilings, a generous, open sales area is constructed over the first four storeys, transforming the containers into a single thermal and fire-safety unit, inside which the various products are presented, sold, and stored. Architizer. "Freitag Flagship Store by Spillmann Echsle Architekten," Retrieved 11.07.2023, from: https://architizer.com/projects/freitag-flagship-store/	*No*	*Yes*	*Slowing, Closing*	*Dematerialization and lightweight construction* *Design for reversibility* *Secondary materials and components* *Waste prevention/reduction during construction*	*Both*	*No*	Moos Heunicke & Vejlgaard, 2021

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29	Building D(emountable)	Year: 2019 Type: Office Location: Delft, NL Architect: Cepezed Developer: Cepezed Size: 968 m2 StructureMA: Hybrid StructureSY: Column/Beam Flexibility: Technical Principle 1: Reconfiguring Principle 2: Replaceability	Building D(emountable) is a modern, sustainable and fully demountable structure on the site of a historic, monumental building complex in the center of Dutch city Delft. In addition to being demountable and mountable, the structure is also super lightweight: the use of materials is kept to an absolute minimum. The building is also completely flexible in its arrangement, has no gas connection and is equipped with heat recovery. The ground floor is made of poured concrete, but otherwise, all building components are modular and dry mounted. Supreme simplicity has been an important principle in the design. Steel, wood, and glass. Building part D(emountable) consists of a rationally optimized building kit with steel, prefabricated and extremely slender main supporting structure. The structural floors and roof are made of lightweight wooden Laminated Veneer Lumber (LVL) elements that are also prefabricated. These have a compact height and the installations are integrated into them. The different construction components were put together with the minimum of connections. The connections were designed to remain reversible, meaning that the building can be easily dismantled. The office approaches circular construction and will in the future be able to donate building materials to other projects. *“Fast Construction with Hybrid Structures.” Retrieved 11.07.2023, from: https://www.metsagroup.com/metsawood/news-and-publications/news/2020/building-demountable--fast-construction-with-hybrid-structures/*	*Yes*	*Yes*	*Narrowing, Slowing*	*Dematerialization and lightweight construction* *Design for reversibility* *Avoidance of (carbon-intensive) components and structural elements* *Resource efficiency in construction*	*Both*	*No*	Moos Heunicke & Vejlgaard, 2021
30	Waterloo City Farm	Year: 2018 Type: Educational Location: London, UK Architect: Feilden Fowles Architects Developer: n.a. Size: 423 m2 StructureMA: Timber StructureSY: Column/Beam Flexibility: Technical Principle 1: Accessibility Principle 2: Separation	Nestled in bustling London this collective team have created a site that is an oasis. The site hosts visits by local school groups, community activities and external events. The site includes a design studio, animal pens, a classroom, planting, central yard and barn. Versatile in use, all the structures are designed to be temporary and demountable. Therefore, all fixings are mechanical. This means the collective cluster on the site can potentially move to another location in the future. *“Waterloo City Farm.” Retrieved 11.07.2023, from: https://www.feildenfowles.co.uk/waterloo-city-farm/*	*No*	*Yes*	*Slowing*	*Dematerialization and lightweight construction* *Design for reversibility* *Design for reuse* *Materials with low embodied carbon* *Avoidance of (carbon-intensive) components and structural elements*	*Both*	*No*	Moos Heunicke & Vejlgaard, 2021

#	Project Name	Data	Description	Built with CE principles in mind (Y/N)	Adheres to CE Principles or has followed circular building strategies (Y/N)	CE Categories of Principles applied	Circular building strategies applied	Circular in/out/both?	Has building been dismantled / recycled / demolished?	Source
31	Gymnasium Nord	Year: 2019 Type: Educational Location: Frankfurt, DE Architect: Dach + Holzbau Developer: n.a. Size: n.a. StructureMA: Timber StructureSY: Box-construction Flexibility: Technical Principle 1: Accessibility Principle 2: Replaceability	In order to construct new school buildings in a short period of time, several temporary school buildings have been erected in Frankfurt in recent years using timber modular construction, including the Gymnasium Nord in Westhausen, which started operations in 2016. The Gymnasium serves as a temporary location; it has not yet been determined where the school will later be permanently located. In 2018, the Gymnasium was expanded to include several buildings in wood modular construction. Each of the 210 modules was transported to its destination by crane and assembled. Three modules form a classroom measuring around 60 m2. The three-story school building was thus erected in just a few weeks. *"Schule mit Holzmodulen erweitert - dach+holzbau." Retrieved 11.07.2023, from: https://www.dach-holzbau.de/artikel/schule-mit-holzmodulen-erweitert-3409397.html*	*No*	*Yes*	*Slowing, Closing*	*Design optimization* *Dematerialization and lightweight construction* *Design for reversibility* *Design for reuse* *Materials with low embodied carbon* *Avoidance of (carbon-intensive) components and structural elements* *Resource efficiency in construction*	*Both*	*No*	Moos Heunicke & Vejlgaard, 2021
32	Wood Nursery	Year: 2020 Type: Educational Location: Paris, FR Architect: Djuric Tardio Architectes Developer: n.a. Size: 525 m2 StructureMA: Steel StructureSY: Column/Beam Flexibility: Technical Principle 1: Replaceability Principle 2: Separation	The request for proposals issued by the municipal government of Paris was an opportunity to implement this system to build a 48-cradle nursery. Modular and nomadic, the building fulfills the requirements for rehousing Parisian children deprived of their usual child care establishments undergoing works. Thus, the building is designed to be disassembled, moved and reassembled. This high-performing and bio-sourced building was designed with the principle of reversibility. It can be entirely reconfigured to be utilized for this program or others (emergency housing, offices, etc.), in order to serve new needs and future uses. The Luxembourg site will be identically returned to its original state in two years and the building will be erected elsewhere. The design of the nursery is based on a primary dismountable structure inspired by a construction system of Jean Prouvé's, enabling the manipulation of self-bearing modules. The assemblages are borrowed from traditional Japanese systems. The structural envelope is prefabricated in the workshop and the interior layout and utilities are also modular. ArchDaily. "Wooden Nursery / Djuric Tardio Architectes," Retrieved 11.07.2023, from: https://www.archdaily.com/935476/wooden-nurserydjuric-tardio-architectes	*No*	*Yes*	*Slowing, Closing*	*Design optimization* *Dematerialization and lightweight construction* *Design for reversibility* *Design for reuse* *Materials with low embodied carbon* *Avoidance of (carbon-intensive) components and structural elements*	*Both*	*No*	Moos Heunicke & Vejlgaard, 2021

#	Project Name	Data	Description	Built with CE principles in mind (Y/N)	Adheres to CE Principles or has followed circular building strategies (Y/N)	CE Categories of Principles applied	Circular building strategies applied	Circular in/out/both?	Has building been dismantled / recycled / demolished?	Source
33	People's Pavilion	Year: 2017 Type: Pavilion Location: Eindhoven, NL Architect: Bureau SLA + Overtreders W Developer: n.a. Size: 250 m2 StructureMA: Hybrid StructureSY: Hybrid Flexibility: Technical Principle 1: Replaceability Principle 2: Accessibility	The pavilion is a design statement of the new circular economy, a 100% circular building where no building materials were lost in construction. All building materials were borrowed, with an exception for facade consisted of colored plastic tiles, made of recycled plastic household waste, collected largely by Eindhoven inhabitants. Borrowed materials means a construction site without screws, glue, drills or saws. The base for the People's Pavilion was a construction of 12 concrete foundation piles and 19 wooden frames. The frames consisted of unplaned wooden beams of standard dimensions, held together with steel straps. Concrete piles and frames were connected with 350 tensioning straps, creating an eight-meter-high primary structure. ArchDaily. "People's Pavilion / Bureau SLA + Overtreders W," Retrieved 11.07.2023, from: https://www.archdaily.com/915977/peoples-pavilionbureau-sla-plus-overtreders-w	*Yes*	*Yes*	*Slowing, Closing*	*Design for reversibility* *Design for reuse* *Secondary materials* *Reuse of (carbon-intensive) components and structural elements* *Waste prevention/reduction during construction*	*Both*	*Yes*	Moos Heunicke & Vejlgaard, 2021
34	Circular Shade House	Year: 2019 Type: Community Location: Paris, FR Architect: WAO Developer: n.a. Size: 175 m2 StructureMA: Timber StructureSY: Column/Beam Flexibility: Technical Principle 1: Reconfiguring Principle 2: Replaceability	Circular Shade House is made from 90% reclaimed wood. It is a structural and architectural demonstration of three success stories: a collective, a circular economy approach, and a practical application of the international Fab City movement. The project commissioned by Les Canaux needed to shade the organization's activities from the sun during the summer, with the ambition of using almost exclusively reused or reclaimed materials and designing, sourcing and building the structure in just two months. The entire structure was completed just in time, and remained intact until is dismantlement. Instead of following the linear consumerist path where products are transported then discarded, we adopted a circular approach, producing goods from waste materials, and where data circulates freely among cities, in order to diffuse these strategies. ArchDaily. "Canaux's Circular Shade House / WAO," Retrieved 11.07.2023, from: https://www.archdaily.com/935063/canauxs-circularshade-house-wao	*Yes*	*Yes*	*Slowing, Closing, Regenerating*	*Design for reversibility* *Design for reuse* *Secondary materials* *Avoidance of (carbon-intensive) components and structural elements*	*Both*	*Yes*	Moos Heunicke & Vejlgaard, 2021

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35	Østre Havn Parking House G2	Year: 2018 Type: Parking Location: Aalborg, DK Architect: SANGBERG Architects Developer: n.a. Size: 15,200 m2 StructureMA: Concrete StructureSY: Column/Beam Flexibility: Technical Principle 1: Replaceability Principle 2: Reconfiguring	The parking house in Østre Havn, has a simple facade that varies according to the light of the sun and sky. Located between Nyhavnsgade and Østre Havngade, the parking house has a robust construction from simple materials, in-keeping with the former industrial aesthetics of its harbor context. Its facades consist of a range of different extruded aluminum lamellas, which are easy to assemble, and therefore also easy to disassemble. This ensures that at the end of the building's life all of the facade materials can be easily dismantled, and the aluminum can be recycled. ArchDaily. "Østre Havn Parking House G2 / SANGBERG Architects," Retrieved 11.07.2023, from: https://www.archdaily.com/929530/ostre-havnparking-house-g2-sanberg-architects.	*No*	*Yes*	*Closing*	*Design for reversibility*	*Out*	*No*	Moos Heunicke & Vejlgaard, 2021
36	Modular housing	Year: 2021 Type: Mixed-Use Location: Bro, SE Architect: n.a. Developer: Algeco StructureMA: Hybrid StructureSY: Box-construction Flexibility: Technical Principle 1: Reconfiguring Principle 2: Separation	Algeco is providing modular housing units for public and private use. The buildings have a high degree of flexibility and is moveable and easy to expand when needed. It is easy to disassemble parts of the building and put it together in new configurations. Algeco is selling housing units, but mainly they rent them out. "Modulbyggnader till Privat Och Offentlig Sektor | Algeco." Retrieved 11.07.2023, from: https://www.algeco.se/produkter/modulbyggnader	*Yes*	*Yes*	*Slowing*	*Design for reversibility* *Resource efficiency in construction*	*Out*	*Unknown*	Moos Heunicke & Vejlgaard, 2021
37	The Crystal Palace	Year: 1851 Type: Pavilion Location: London, UK Architect: Joseph Paxton Developer: Size: 91,974 m2 StructureMA: Steel StructureSY: Column/Beam Flexibility: Technical Principle 1: Replaceability Principle 2: Accessibility	The Crystal Palace at Sydenham is an early example of design for disassembly that was built before the DfD concept even existed. It was built in Hyde Park, London to house the Great Exhibition of 1851. Made of cast iron and plate glass, building was designed to be temporary, simple, cheap and easy to transport. Its modular panels were packed up and moved to South London for reassembly, and it remained there until its destruction by fire in 1936. WebUrbanist. "Designed for Disassembly: Architecture Built with Its Own End in Mind," Retrieved 11.07.2023, from: https://weburbanist.com/2018/11/21/designed-for-disassembly-architecture-built-with-its-own-end-in-mind/	*No*	*Yes*	*Slowing*	*Design for reuse*	*Out*	*Yes (after being destroyed by fire)*	Moos Heunicke & Vejlgaard, 2021

#	Project Name	Data	Description	Built with CE principles in mind (Y/N)	Adheres to CE Principles or has followed circular building strategies (Y/N)	CE Categories of Principles applied	Circular building strategies applied	Circular in/out/both?	Has building been dismantled / recycled / demolished?	Source
38	Portable Foldable Buildings	Year: 1986 Type: Building system Location Istanbul, TR Architect: n.a. Developer: Karmod Size: n.a. StructureMA: Composite StructureSY: Walls/Slab Flexibility: Technical Principle 1: Separation Principle 2: Reconfiguring	Karmod is a Turkey-based prefab design and manufacturing company producing buildings that are a combination of modular and panelized. Because of the Flat-Pak collapsible design features, these buildings are useful for applications such as low cost or temporary housing, but also permanent buildings. Karmod products, which are produced as disassembled and pre-produced, are easy to deliver and fast to install. Rugged, lightweight, versatile and energy efficient, Karmod portable Foldable buildings are easy and quick to assemble. They are available for a wide range of applications, featuring numerous configurations and amenity combinations. One of the most important features of modular structures is that they can easily be expanded. “Foldable Buildings & Structures - Prefab Folding House | Karmod.” Retrieved 11.07.2023, from: https://karmod.eu/blog/versatile-foldable-building/	*No*	*Yes*	*Slowing*	*Design for reversibility*	*Out*	*Unknown*	Moos Heunicke & Vejlgaard, 2021
39	U-Build	Year: 2017 Type: Building system Location: London, UK Architect: Studio Bark Developer: Structure Workshop, Cut and Construct Size: n.a. StructureMA: Timber StructureSY: Hybrid Flexibility: Technical Principle 1: Accessibility Principle 2: Reconfiguring	U-Build is a highly flexible unique system made from strong lightweight modular boxes which connect to form larger objects. This means that they can be used to build almost anything. The most popular designs are studios, houses, and interior projects. Using only a mallet and a drill, 1-2 people can easily assemble the boxes. Using standard connections, the boxes bolt together, creating a rigid frame for your new space. Being modular, U-Build is totally demountable and expandable so it can grow and move. U-Build is conceived as a low-impact building system suitable for the circular economy, where all parts are fully demountable and recyclable. The system is made of flat pack wooden panels which are produced using a computer controlled cutting machine (CNC) and are accurate to 0.1 of a millimetres. Many of the solutions do not require concrete foundations, meaning they can sit on the ground with a light touch. U-Build. “U-Build by Studio Bark Is a Revolutionary Self-Build Flat Pack System.” Retrieved 11.07.2023, from: https://u-build.org/.	*Yes*	*Yes*	*Slowing, Closing*	*Design Optimization* *Dematerialization and lightweight construction* *Design for reversibility* *Materials with low embodied carbon* *Avoidance of (carbon-intensive) components and structural elements* *Resource efficiency in construction* *Waste prevention/reduction during construction* *Low-carbon construction equipment*	*Both*	*Unknown*	Moos Heunicke & Vejlgaard, 2021

#	Project Name	Data	Description	Built with CE principles in mind (Y/N)	Adheres to CE Principles or has followed circular building strategies (Y/N)	CE Categories of Principles applied	Circular building strategies applied	Circular in/out/both?	Has building been dismantled / recycled / demolished?	Source
40	WikiHouse	Year: 2021 Type: Building system Location: London, UK Architect: n.a. Developer: Open Systems Lab Size: n.a. StructureMA: Timber StructureSY: Hybrid Flexibility: Technical Principle 1: Accessibility Principle 2: Reconfiguring	WikiHouse is a timber building system made of manufactured components which can be rapidly assembled by almost anyone. WikiHouse is an adaptable system of standardised parts. This means each house can be unique without costing more. One size doesn't need to fit all. WikiHouse doesn't need a large, expensive factory. Components are manufactured by a network of local microfactories using digital fabrication tools. WikiHouse is open source – that means the files are shared for anyone to use and improve – and is being contributed-to and used by a community of designers and engineers around the world. Homes can be rapidly assembled to millimetre precision, like a flat-pack. Almost anyone can do it; including small businesses and self-builders. The aim of the project is to put the tools and knowledge to build beautiful, zero-carbon, zero-waste homes into the hands of everyone. 80-90 % of the components are reuseable. "WikiHouse." Retrieved 11.07.2023, from: https://www.wikihouse.cc	*Yes*	*Yes*	*Slowing, Closing*	*Design Optimization* *Dematerialization and lightweight construction* *Design for reversibility* *Materials with low embodied carbon* *Avoidance of (carbon-intensive) components and structural elements* *Resource efficiency in construction* *Waste prevention/reduction during construction* *Low-carbon construction equipment*	*Both*	*Unknown*	Moos Heunicke & Vejlgaard, 2021
41	PLACE/Ladywell	Year: 2016 Type: Mixed-Use Location: London, UK Architect: Rogers Stirk Harbour + Partners Developer: Lewisham Council, AECOM, SIG Build Size: 2,990 m2 StructureMA: Timber StructureSY: Column/Beam Flexibility: Technical Principle 1: Replaceability Principle 2: Separation	PLACE/Ladywell aims to create a deployable residential development using a volumetric construction method. It responds to the high demand for housing in the Borough by offering a short-term solution. The volumetric technology provides high quality, energy efficient accommodation and means that the development can be built faster and cheaper than if traditional methods were used. The finished structure is also fully demountable meaning it could, after 4 years at the initial site be relocated elsewhere at a permanent site or be divided up into smaller projects according to site availability. The building is arranged into three blocks divided by two external cores. It is constructed as 64 individual fully finished units stacked in a 4 storey arrangement, all manufactured in a factory in Nottinghamshire. *"PLACE /Ladywell - Rogers Stirk Harbour + Partners." Retrieved 11.07.2023, from: https://rshp.com/projects/residential/place-ladywell/*	*No*	*Yes*	*Slowing, Closing*	*Dematerialization and lightweight construction* *Design for reversibility* *Avoidance of (carbon-intensive) components and structural elements* *Resource efficiency in construction* *Waste prevention/reduction during construction*	*Both*	*No*	Moos Heunicke & Vejlgaard, 2021

#	Project Name	Data	Description	Built with CE principles in mind (Y/N)	Adheres to CE Principles or has followed circular building strategies (Y/N)	CE Categories of Principles applied	Circular building strategies applied	Circular in/out/both?	Has building been dismantled / recycled / demolished?	Source
42	London 2012 games basketball arena	Year: 2011 Type: Stadium Location: London, UK Architect: Wilkinson Eyre architects, KSS design group Developer: Barr Construction Size: 11,500 m2 StructureMA: Steel StructureSY: Column/Beam Flexibility: Technical Principle 1: Replaceability Principle 2: Separation	The Basketball Arena by Wilkinson Eyre Architects is one of the biggest temporary venues ever erected for any Olympic and Paralympic Games and the third largest venue in the Olympic Park. Located on high ground at the north end of the site, and clearly visible from various vantage points in the Olympic Park, the Arena provided 12,000 seats for the basketball heats and handball finals, as well as 10,000 seats for the wheelchair basketball and wheelchair rugby competitions. The brief called for a structure that was simple to erect but also provided a world-class sporting venue for some of the most popular Olympic events. Alongside these factors, sustainability was a key driver in the building's design: the arena has been made out of robust individual components that can be easily dismantled and subdivided for reuse, with over two-thirds of the materials and components used on the project identified for reuse or for recycle. The 30m high rectangular volume is made out of a steel portal frame and wrapped in 20,000 sqm of lightweight phthalate-free and recyclable PVC. In January 2013 the arena was dismantled, the seating was sold to Barnet F.C owner Tony Kleanthous to be used in the construction of The Hive Stadium. ArchDaily. "London 2012 Basketball Arena / Wilkinson Eyre Architects," Retrieved 11.07.2023, from: https://www.archdaily.com/255557/london-2012-basketball-arena-wilkinson-eyre-architects	*No*	*Yes*	*Slowing, Closing*	*Design for reversibility* *Design for reuse*	*Out*	*Yes*	Moos Heunicke & Vejlgaard, 2021
43	Top-Up	Year: 2020 Type: Mixed-use Location: Amsterdam, NL Architect: n.a. Developer: n.a. Size: 99-1496m2 StructureMA: Hybrid StructureSY: Column/Beam Flexibility: Technical Principle 1: Replaceability Principle 2: Reconfiguring	Top-Up is a new construction project on the Johan van Hasselt Canal in Buiksloterham, Amsterdam North. The building is flexible and circular: the function of the building can change, and the building materials can be reused. The Top-Up building can be completely transformed in the long term. The walls between the different apartments are not loadbearing. The lofts can therefore grow and shrink. Now or in the future. Due to the free height of 3 meters, the building can eventually be transformed into other functions, such as an office, school or hotel, and then back to the apartment building. At the end of its life cycle, Top-Up can largely be dismantled and the raw materials, such as wood, glass, aluminum, and concrete, can be used for a new building. The concrete construction of the ground floor is the only part that cannot be dismantled, but this is a reused concrete construction of the former concrete cable reel of the PTT, which is currently still on the site. Top-Up Amsterdam. "Duurzaamheid." Retrieved 11.07.2023, from: https://www.top-up.amsterdam/duurzaamheid/	*Yes*	*Yes*	*Slowing, Closing*	*Design for reversibility* *Avoidance of (carbon-intensive) components and structural elements*	*Both*	*No*	Moos Heunicke & Vejlgaard, 2021

#	Project Name	Data	Description	Built with CE principles in mind (Y/N)	Adheres to CE Principles or has followed circular building strategies (Y/N)	CE Categories of Principles applied	Circular building strategies applied	Circular in/out/both?	Has building been dismantled / recycled / demolished?	Source
44	HAUT Timber Tower	*Year: 2022* Type: Residential *Location: Amsterdam, NL* *Architect: Team V* *Developer: Lingotto* *Size: 14,500 m2* *StructureMA: Hybrid* *StructureSY: Walls/Slab* *Flexibility: n.a.* *Principle 1: n.a.* *Principle 2: n.a.*	*The development site of HAUT on the River Amstel did not simply go to the highest bidder. In assessing offers, the municipality of Amsterdam also considered architectural quality and environmental sustainability. The selected proposal for a 21-story residential tower in timber, is one of the tallest timber hybrid structures in the world.* *The load-bearing structure of HAUT is made of cross-laminated timber (CLT) panels manufactured off-site, ensuring low waste production and fast and clean on-site assemblage. As there are no standard building regulations for high-rise timber constructions in the Netherlands, the design team has invested considerable time and energy in technical innovation and safety. Floors and walls are constructed in timber, however a structure made completely of timber in wet and windy Amsterdam would be impossible. Consequently, the foundations, basement, and core are constructed in concrete.* *CLT panels are easily adaptable during prefabrication, offering first buyers options in the size and layout of their apartment, the number of floors, and the positioning of double-height spaces, galleries and balconies. Unlike most timber buildings, only the inner walls of HAUT are load-bearing, which allows for floor-to-ceiling windows in the façade. The irregular pattern of balconies and the pronounced, double-height spaces facing the River Amstel make HAUT's architecture highly distinctive.* *"HAUT," Retrieved 11.07.2023, from: https://teamv.nl/project/haut/*	*No*	Yes	*Slowing, Regenerating*	*Materials with low embodied carbon* *Avoidance of (carbon-intensive) components and structural elements*	*In*	*No*	Nußholz et al. (2023)
45	Juff Nienke	*Year: 2022* Type: Residential *Location: Amsterdam, NL* *Architect: SeARCH, RAU* *Developer: Dokvast* *Size: 7,500 m2* *StructureMA: Timber* *StructureSY: Box-construction* *Flexibility: Technical* *Principle 1: Replaceability* *Principle 2: Reconfiguring*	*The main 15-meter-high wooden structure rests on a concrete base of parking and a commercial plinth. In the semi-underground parking garage, there is space for 25 cars and 246 bikes. The double height transparent plinth will have a cafe, shops, shared workspaces, studios and tutoring spaces.* *The materials used in 'Juf Nienke' are mainly biobased and recycled; they have a low environmental impact and are largely renewable. The prefabricated timber modules (made HSB & partly CLT) can be paired horizontally or stacked vertically to create a variety of housing typologies. By varying the depths of the prefabricated timber modules but keeping a standard width of 4m the housing is completely demountable. This means 'Juf Nienke' can easily be adapted in the future.* *By building the housing entirely out of timber we can store more than 580.000 kg CO2, actively responding to the challenge posed by climate change and contributing to a healthy living environment. By prefabricating the timber housing we can lower the amount of waste, often created during construction, minimize the impact on the surroundings and reduce construction time significantly.* *"Juf Nienke," Retrieved 11.07.2023, from: https://www.search.nl/works/juf-nienke/*	*Yes*	Yes	Narrowing, Slowing, Closing, Regenerating	*Design Optimization* *Dematerialization and lightweight construction* *Design for reversibility* *Materials with low embodied carbon* *Avoidance of (carbon-intensive) components and structural elements* *Waste prevention/reduction during construction*	*Both*	*No*	Nußholz et al. (2023)

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46	Koning Willem I College	*Year: 2021* Type: Educational *Location: 's-Hertogenbosch, NL* *Architect: Nieuwe Architecten* *Developer: n.a.* *Size: 6,501 m2* *StructureMA: Hybrid* *StructureSY: Column/Beam* *Flexibility: Spatial* *Principle 1: Partitioning* *Principle 2: Multi-functionality*	*The new building for the Koning Willem I College in 's-Hertogenbosch (NL) is a progressive 5-story educational building with a completely wooden main supporting structure. All-wood load-bearing structure. Diagonal beams providing stability are placed in the facade, making freely divisible floors possible. The apparently simple wooden knots hide a great complexity of connections in the transmission of forces. The lamination of the wood includes steel plates and connections that transfer the forces with steel pins (over 15,000 pieces!) in the meeting of columns and beams.* *The wood covers all steel connections in such a way that a fire-resistant shell is created. Despite the relatively light wooden construction, there is sufficient mass in the building by combining it with concrete hollow-core slabs. This limits sound transmission and introduce mass for accumulating capacities. The floorplans can be planned within strong modularity of 2m zones with standardized elements that are interchangeable and an installation that follows this modularity. The interior is designed to maintain the value of the material and the ability to retain this value throughout its lifecycle. Conscious and integrated products and materials with a circular approach limit waste during the building phase and reuse of elements during the users' phase.* *"Renewal Koning Willem I College / Nieuwe Architecten," Retrieved 11.07.2023, from: https://www.archdaily.com/975741/renewal-koning-willem-i-college-nieuwe-architecten*	*Yes*	Yes	Slowing, Regenerating	*Dematerialization and lightweight construction* *Waste prevention/reduction during construction*	*In*	*No*	Nußholz et al. (2023)
47	Super Circular Estate (Type A)	*Year: 2019* Type: Residential *Location: Kerkrade, NL* *Architect: SeC Architecten* *Developer: n.a.* *Size: 74 m2* *StructureMA: Concrete* *StructureSY: Walls/Slab* *Flexibility: Unknown* *Principle 1: Unknown* *Principle 2: Unknown*	*The aim of the construction of three new houses was to construct them using at least 75% of reused materials that are re-sourced from a donor building. House Type A has 74m2 and is a two-bedroom house. During construction the following circular techniques have been tested:* *• Foundation has been made out of circular concreate (aggregate and cement for the concrete which have been acquired by crashing the existing concreate structure, only 7% of new cement has been added during production of concrete for the foundation)* *• Main loadbearing structure has been directly reused from the existing building by cutting 3D concrete module from the existing structure,* *• Partitioning walls have been directly reused from the existing building as well as wooden frames for doors, finally façade has been constructed out of modules using crashed concrete pieces from the existing building.* *It is unknown whether the new buildings are DfD-compliant.* *"The Super Circular Estate project Journal N°3," Retrieved 11.07.2023, from: https://www.uia-nitiative.eu/sites/default/files/2020-03/Kekrade_Super%20Circular%20Estate_Journal.pdf*	*Yes*	Yes	Slowing, Closing	*Secondary materials and components* *Reuse of (carbon-intensive) components and structural elements*	*In*	*No*	Nußholz et al. (2023)

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48	Patch 22	*Year: 2016* Type: Residential *Location: Amsterdam, NL* *Architect: Franzen et al* *Developer: Lemniskade* *Size: 5,400 m2* *StructureMA: Timber* *StructureSY: Column/Beam* *Flexibility: Spatial* *Principle 1: Partitioning* *Principle 2: Multi-functionality*	*Patch22 is a seven-story mixed commercial and residential building in the circular Buiksloterham neighborhood of northern Amsterdam. It was newly constructed in 2016 by architect Tom Frantzen and building manager Claus Oussoren, who aimed to produce a building that was simultaneously flexible, durable, and sustainable. The building is constructed entirely from timber and uses solar panels, rainwater collection, and CO2-neutral pellet stoves, making Patch22 entirely energy-neutral. Units are sold devoid of interior walls, wiring, and plumbing, and residents can choose to outfit their space themselves or with the aid of the developer. At the time of construction, it was the tallest timber apartment building in Amsterdam.* *Patch22's core and shell are constructed out of glue-laminated (glulam) and cross-laminated timber (CLT). To prevent moisture from damaging the exposed wood on the building's exterior, the ends of the trusses were capped with steel, and pre-weathered fire-treated Douglas fir was used. The wood members were also made thicker than is structurally necessary in order to meet fire codes. Each unit has no interior structural dividing walls or columns, and floors are hollow with a removable top, meaning that each unit is entirely customizable. Each floor has a central core which houses the elevator and stairwell, and the North and South sides are occupied by large loggias, which can be closed in as desired. Each floor can be divided into as many as eight units or as few as one 5812 square foot apartment.* *Because the floor to ceiling height of each floor is 13 ft, the building can be converted into office or commercial space with no additional construction.* *"Hollandse hout-hoogbouw (1): patch22 amsterdam: van plan tot bouw," Retrieved 11.07.2023, from: http://lemniskade.nl/wp-content/uploads/2017/01/156Patch22-Amsterdam_def.pdf*	*No*	Yes	Slowing, Regenerating	*Design for easy maintenance and repair* *Design for reversibility* *Avoidance of (carbon-intensive) components and structural elements*	*In*	*No*	Nußholz et al. (2023)
49	UMAR Unit (Empa Nest)	*Year: 2017* Type: Pavilion *Location: Dübendorf, CH* *Architect: Werner Sobek* *Developer: n.a.* *Size: 155 m2* *StructureMA: Timber* *StructureSY: Wall/Slab* *Flexibility: Technical* *Principle 1: Accessibility* *Principle 2: Separation*	*In 2018, the "Urban Mining and Recycling" (UMAR) unit by Werner Sobek with Dirk E. Hebel and Felix Heisel has been installed into the NEST building in Dübendorf, Switzerland. NEST stands for "Next Evolution in Sustainable Building Technologies" and represents a modular research and innovation building of Empa (Swiss Federal Laboratories for Material Science and Technologies) and Eawag (Swiss Federal Institute of Aquatic Science and Technology). Here, in the form of various added thematic living and working units, new technologies, materials, operation systems and user behaviours can be tested, researched and validated under realistic conditions, fostering an acceleration of innovation processes in the building sector. The specific aim of the UMAR project is to develop a prototypical living unit (its floor plan is shown in Figure 1 below), which shows the potential for closed material cycles in construction. As the UMAR unit serves as a temporary material bank, a comprehensive designfor-disassembly concept has been conceived already at the beginning of the design and planning stage in order to allow easy access, separation and in-grade sorting of all individual materials at the end of their lifetime.* *Consequently, UMAR consists of a primary, modular de-constructible frame structure with replaceable wall, floor and roof*	Yes	Yes	Slowing, Closing, Regenerating	*Design for reversibility* *Design for reuse* *Materials with low embodied carbon* *Renewable and non-toxic materials* *Secondary materials and components* *Avoidance of (carbon-intensive) components and structural elements*	*Both*	*No*	Nußholz et al. (2023)

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			elements, which are obtained only from reused, recyclable and/or recycled, or compostable materials. Furthermore, no glues, paints, foams or other wet sealants have been used in order to achieve a fully de-constructible building system. The introduction of new business models such as renting of building elements or replacement of materials through digital alternatives are further research objectives of the UMAR unit and its application to a circular construction industry. *"Environmental assessment of the Urban Mining and Recycling (UMAR) unit by applying the LCA framework," Retrieved 11.07.2023, from: https://iopscience.iop.org/article/10.1088/1755-1315/225/1/012043/pdf*							
50	Ressourcerækkerne	*Year: 2019* Type: Residential *Location: Copenhagen, DK* *Architect: Lendager Group* *Developer: Lendager Group* *Size: 9,148 m2* *StructureMA: Concrete* *StructureSY: Wall/Slab* *Flexibility: n.a.* *Principle 1: n.a.* *Principle 2: n.a.*	*With the client we wanted to explore how future cities can make the best use of all available resources. We concluded harvesting materials from old buildings is the future of new build. The materials have been harvested and put into production by the architects. We developed methods for scaling the reuse of untapped resources in "construction waste" to build new homes, using sustainable, non-toxic and certified materials! The result show that the utilization of existing resources has a positive direct impact on the environment! By reusing waste wood and the walls from abandoned buildings as new facade elements, we save CO2 and virgin materials, while also getting a new building with history and character. These inherent stories also function as shared references binding the tenants closer together socially. The blocks are made with a double skin structure. However, in the terraced houses, the outer brick panel skin is tied back to an inner timber frame.* *Recycle materials includes façade bricks and aluminum, internal floors, exterior wood for terraces and decking and roof top houses including the windows. The exterior timber was waste form the crates used for transporting concrete element for the Copenhagen Metro. The wood has been applied an old Japanese technique charring the surface with fire to impregnate it.* *"NREP Impact 2020 report," Retrieved 11.07.2023, from: https://nrep.com/wp-content/uploads/2021/01/NREP-Sustainability-Report-2020-1.pdf*	*Yes*	Yes	Slowing, Regenerating	*Design for reuse* *Secondary materials and components* *Waste prevention/reduction during construction*	*In*	*No*	Nußholz et al. (2023)
51	Erlev Skole	*Year: 2021* Type: Educational *Location: Haderslev, DK* *Architect: Arkitema* *Developer: Ommen A/S* *Size: 5,800 m2* *StructureMA: Timber* *StructureSY: Column/Beam* *Flexibility: n.a.* *Principle 1: n.a.* *Principle 2: n.a.*	*The main architectural concept is based on the principle of a supported forest-like grid of columns in a fixed modular system. Some of the trees in the 'forest' have been 'felled' to create clearings with high ceilings and beautiful natural lighting. Elsewhere, more condensed spaces and cave-like niches have been formed. Like in the great outdoors.* *The load-bearing structure of the school is made of cross-laminated timber (CLT), a material that creates a visually attractive building and emphasizes environmental values. Through timber, the sensory experience becomes stronger; the scent, feeling, and sound of this material create an environment that comes alive through warm and visually interesting surfaces.* *"Erlev School / Arkitema," Retrieved 11.07.2023, from: https://www.archdaily.com/971052/erlev-school-arkitema*	*No*	Yes	Regenerating	*Materials with low embodied carbon* *Renewable and non-toxic materials* *Avoidance of (carbon-intensive) components and structural elements*	*In*	*No*	Nußholz et al. (2023)

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52	The Cradle	*Year: 2023* Type: Office *Location: Düsseldorf, DE* *Architect: HPP Architekten* *Developer: Interboden* *Size: 6,600 m2* *StructureMA: Hybrid* *StructureSY: Column/Beam* *Flexibility: Technical* *Principle 1: Accessibility* *Principle 2: Separation*	*In Düsseldorf's Media Harbour district, the city's first office building in timber hybrid construction – a circular pilot project in many respects. With its futuristic sustainability concept and striking architecture, the Cradle-to-Cradle (C2C) inspired building stands for innovation, openness and a new perception of architecture.* *The holistic value-adding concept has been central right from the start, so that in all processes the thinking is cyclic and equal consideration is given to economic, ecological and social aspects – along the entire value chain and the entire life cycle.* *The laconic rhombic structure combines facade and supporting structure and was developed out of the conditions of the location (orientation, urban context, light and shade, etc.). Designed parametrically in 3D, the externally positioned supporting structure of the building also fulfils a shading function since the depth of the recesses varies according to orientation. Thus, the materiality, geometry and construction themselves clearly reflect the integral themes: sustainability, sun protection, supporting structure and visual reference to the harbour basin. The recesses created by the supporting structure and facade face the harbour and provide functional loggias.* *"The Cradle," Retrieved 11.07.2023, from: https://www.hpp.com/en/projects/fallstudien/the-cradle/*	*Yes*	Yes	Closing, Regenerating	*Design for reversibility* *Design for reuse* *Materials with low embodied carbon* *Renewable and non-toxic materials* *Avoidance of (carbon-intensive) components and structural elements*	*Both*	*No*	Nußholz et al. (2023)
53	The Flat House	*Year: 2019* Type: Residential *Location: Cambridgeshire, UK* *Architect: Practice Architecture* *Developer: n.a.* *Size: 100 m2* *StructureMA: Hempcrete* *StructureSY: Elements* *Flexibility: Technical* *Principle 1: Accessibility* *Principle 2: Separation*	*Situated at Margent Farm, a rural R+D facility developing bio-plastics with hemp and flax, Flat House is a ground breaking radically low embodied carbon house. The three bedroom house was designed with the aim of prototyping pre-fabricated sustainable hemp-based construction to be applied to larger scales of house-construction. Working closely with engineers and material specialists we developed a prefabricated panel infilled with hemp grown on 20 acres of the farm. The elements were raised into place in just two days.* *The main body of the house is constructed out of 'hempcrete' – a mixture of hemp shiv (the woody core of the plant) and lime. It was decided at an early stage that this project should not only demonstrate the environmental and structural benefits of using hemp as a material, but that it should also do so in a way which is scalable. For this reason, the building is constructed from prefabricated hempcrete panels, based on timber I-joists with a hempcrete infill. These panels can be easily disassembled at the end of their life and either re-used or mulched and composted back into the soil.* *"MARGENT FARM: FLAT HOUSE," Retrieved 11.07.2023, from: https://www.bitc.org.uk/wp-content/uploads/2020/09/BITC_Casestudiesdoc_AdvancingCircularConstruction_September2020.pdf*	*Yes*	Yes	Slowing, Regenerating	*Design optimization* *Dematerialization and lightweight construction* *Design for reversibility* *Materials with low embodied carbon* *Renewable and non-toxic materials* *Avoidance of (carbon-intensive) components and structural elements.* *Resource efficiency in construction*	*Both*	*No*	Nußholz et al. (2023)

#	Project Name	Data	Description	Built with CE principles in mind (Y/N)	Adheres to CE Principles or has followed circular building strategies (Y/N)	CE Categories of Principles applied	Circular building strategies applied	Circular in/out/both?	Has building been dismantled / recycled / demolished?	Source
54	Villa Welpeloo	*Year: 2009* Type: Residential *Location: Enschede, NL* *Architect: Superuse Studios* *Developer: n.a.* *Size: 400 m2* *StructureMA: Steel* *StructureSY: Collumn/Beam* *Flexibility: n.a.* *Principle 1: n.a.* *Principle 2: n.a.*	*Welpeloo's creators made sure that the project clearly states the meaning of utility and sustainability. The designing and building of Villa Welpeloo occurred backwards. The architects started off by finding and collecting materials from local factories and warehouses and then designed a structure that best employed those resources. The main characteristic of the house is that it was constructed from almost entirely salvaged materials. Through a process the architects called recyclicity, 60% of the exterior and nearly 90% of the interior are composed of reused and repurposed materials. To decrease the carbon footprint even more, all the materials were obtained within a nine mile radius of the construction site.* *The load bearing construction is made from steel beams from a paternoster (industrial lift). A single machine provided enough steel to construct the whole frame. The main facades are built with wood from damaged cable reels, which have a standard size and are normally used for particleboard or for burning. The insulation was provided by leftover polystyrene panels from a caravan manufacturer. Old billboards were turned into cabinets and broken umbrella spokes into low-voltage lighting.* *The waste materials provided inspired the development of the design. The found materials demanded new shapes and construction methods.* *"VILLA WELPELOO," Retrieved 11.07.2023, from: https://www.csustentavel.com/en/villa-welpelo-i-casa-reciclada/*	*No*	Yes	Slowing, Closing, Regenerating	*Design for durability and long-life* *Secondary materials and components* *Reuse of (carbon-intensive) components and structural elements*	*In*	*No*	Nußholz et al. (2023)
55	Temporary District Courthouse	*Year: 2016* Type: Public *Location: Amsterdam, NL* *Architect: Cepezed* *Developer: Cepezed* *Size: 5,400 m2* *StructureMA: Hybrid* *StructureSY: Column/Beam* *Flexibility: Technical* *Principle 1: Reconfiguring* *Principle 2: Separation*	*While new permanent accommodation is being built on the same plot, jurisdiction is continuing in the temporary new building. On every scale, we searched for possibilities to reduce, reuse and recycle materials. Together with engineering firm IMd, we developed for instance a special attachment system for the hollow-core slab floors, which simplifies detaching and reusing the floor slabs as much as possible.* *Reuse does not just concern the components, it even applies to the entire building: after the first period of use, it can be reassembled in its entirety at a different location, if desired also in a different configuration.* *The building will be disassembled in the same way at Kennispark Twente in Enschede. Almost all the elements are moving with it, except for the cell blocks. There is no need for them in the new function of a business centre.* *"temporary court Amsterdam," Retrieved 11.07.2023, from: https://www.cepezed.nl/en/project/temporary-court-amsterdam/30529/*	*Yes*	*Yes*	*Slowing, Closing*	*Design for reversibility* *Design for reuse* *Reuse of (carbon-intensive) components and structural elements*	*Out*	*Yes*	Author's own database

#	Project Name	Data	Description	Built with CE principles in mind (Y/N)	Adheres to CE Principles or has followed circular building strategies (Y/N)	CE Categories of Principles applied	Circular building strategies applied	Circular in/out/both?	Has building been dismantled / recycled / demolished?	Source
56	Floating Office	*Year: 2021* Type: Office *Location: Rotterdam, NL* *Architect: Powerhouse* *Developer: RED Company* *Size: 4,500 m2* *StructureMA: Timber* *StructureSY: Column/Beam* *Flexibility: Technical* *Principle 1: Accessibility* *Principle 2: Separation*	*A modular, timber building on a floating platform, with a deceptive simplicity. The three-storey building is constructed on a set of 15 "concrete barges" that allow it to float on Rotterdam's Rijnhaven, a former industrial harbour on the Maas river.* *A wooden structure, including cross-laminated timber (CLT) floor slabs, contributes to the building's low carbon footprint and also ensures it is light enough to float. The wooden structure consists of prefabricated frames that were simply screwed together on-site, meaning they could be disassembled and recycled in the future.* *"Floating Office Rotterdam (FOR)," Retrieved 11.07.2023, from: https://www.powerhouse-company.com/floating-office-rotterdam*	*Yes*	*Yes*	*Slowing, Regenerating*	*Design for reversibility* *Design for reuse* *Materials with low embodied carbon* *Renewable and non-toxic materials* *Avoidance of (carbon-intensive) components and structural elements* *Waste prevention/reduction during construction*	*Both*	*No*	Author's own database

Appendix B - Examples of circular materials

The primary input for the tables has come from the Flemish circular building materials database (accessible through: https://www.c-bouwers.be/). The input has (1) been qualitatively reviewed and (2) the author has discarded any materials in the database where the link to the manufacturers' pages was broken and/or data on the material could not otherwise be retrieved. Other input has come from the knowledge of the author, or through suggestions made by consulted colleagues.

The materials are presented in different 'layers', as described by Brand (1994).

The end-result is a non-exhaustive database, of which the author believes that it represents a showcase of the current state circular materials in a European context.

The following needs to be noted regarding the data in specific columns of the table:

- Column B: 'Category' refers to the type of material under examination.
    a. 'Biodegradable' includes those materials that are biodegradable <u>also after application</u>
    b. 'Traditional' includes those materials that may be considered traditional in the construction industry (e.g., concrete, steel, wood)
    c. 'Hybrid' includes those materials that are formed by (1) a combination of traditional materials, and (2) a combination of a traditional material with an additive
    d. 'Innovative' includes those materials that are not captured by the aforementioned categories
- Column E: Built with CE principles in mind means the building itself, its design or construction is advertised as being circular by its stakeholders
- Column G: 'CE Categories of Principles applied' refers to the explanations given in Nußholz et al. (p.2, 2023)
- Column H: 'Possibilities for application in following circular strategies' refers to the strategies presented for new built projects in Nußholz et al. (p.2, 2023)
- Column I: The 'Circular in/out/both?' assesses whether the examined material considers the materials and products going IN the production of the material, the materials and products coming OUT after its application in a building, or whether BOTH are taken into account.
- Column J: 'Real world application (Y/N)' examined whether the assessed materials have been applied in realized projects. References given by the manufacturer have been used to make the assessment. Reach of application has been described in column K.

Structure

#	Category	Material category	Name	Producer	Description	Circular categories of principles	Possibilities for application in following circular strategies	Circular In/Out/ Both	Real world application (Y/N)	Applied projects	Source (all data retrieved from sources between 9.8.2023 – x.x.2023)
1	Traditional	Concrete	Various	Various	Concrete that uses a certain % of (reused) aggregates and/or waste materials/slags	Closing	Secondary materials and components Avoidance or reuse of (carbon-intensive) components and structural elements	In	Yes	Various projects around Europe/World	https://www.holcim.com/what-we-do/our-building-solutions/ready-mix-concrete/ecopact#holcim-section-7, https://www.hyperionrobotics.com/product-services
2	Hybrid	Concrete	Susteno	Holcim	Susteno is made possible by processing and upcycling materials from demolition projects, resulting in a cement that closes the loop on CDW to build new from the old and preserve nature. Susteno reduces the clinker content of the cement and therefore its CO2 by 10% compared to an already CO2-optimized Swiss mass cement. Clinker is the most CO2 intensive component of cement with roughly two-thirds of CO2 emitted as a result of the chemical reaction in the manufacturing process. This means that the most meaningful way to reduce CO2 emissions of cement is by replacing clinker with mineral components. Since common substitute materials like fly ash and slag are not available in Switzerland, Holcim invented alternative local solutions based on gypsum and burned slates, which also shortens logistics distances.	Closing	Secondary materials and components Avoidance or reuse of (carbon-intensive) components and structural elements	In	Yes	Several projects in Switzerland	https://www.holcim.com/what-we-do/our-building-solutions/cement/susteno
3	Hybrid	Concrete & Carbon	Carbonaide	Carbonaide	Carbonaide solution is based on an effective carbonation method, which allows binding carbon dioxide into concrete blocks using an automated system at atmospheric pressure. The method is compatible with the current manufacturing processes of concrete. It can be used for manufacturing all precasted concrete elements and products. When industrial side streams are used in the process, instead of normal cement, the result is concrete with a negative carbon footprint. Among the possible side streams, steel industry slags, green liquor dregs and bio-ash have been combined successfully in laboratory scale.	Closing	Design for durability and long-life Avoidance or reuse of (carbon-intensive) components and structural elements	In	No	-	https://carbonaide.com/news/vtts-carbonaide-technology-for-manufacturing-carbon-negative-concrete-awarded-by-earto/
4	Innovative	Geopolymer concrete	Geoprime, Gepocit	Betolar, Apila	The Geoprime products are based on a geopolymer solution. A geopolymer is an inorganic polymer that can be used for creating new materials, for example, to replace concrete. Geoprime concrete consists of components from industrial side streams and Betolar's proprietary Geoprime activator, but no climate-unfriendly cement.	Closing	Design for durability and long-life Avoidance or reuse of (carbon-intensive) components and structural elements	In	No	-	https://geoprime.betolar.com/ https://www.apilagroup.fi/en/gepocit/

#	Category	Material category	Name	Producer	Description	Circular categories of principles	Possibilities for application in following circular strategies	Circular In/Out/ Both	Real world application (Y/N)	Applied projects	Source (all data retrieved from sources between 9.8.2023 – x.x.2023)
5	Hybrid	Concrete	Orbix blocks, Masterbloc	Orbix, NV Betonagglo meraten Gubbels	The blocks are particularly sturdy stacking blocks, which are extremely suitable for building walls and storage boxes. They are made of mixtures which contain a certain % of materials that originate from waste streams. Their size and unique shape make building with the blocks child's play: they are stacked to form a stable wall. In addition, they are resistant to X-rays. This makes them very suitable as protection against radiation, for example for a radiation bunker.	Closing	Secondary materials and components Avoidance or reuse of (carbon-intensive) components and structural elements	Both	Yes	Various projects in Belgium and The Netherlands	https://www.orbix.be/nl/materialen/orbixblokken, https://www.masterbloc.be/
6	Hybrid	Steel (Reversible concrete column connectors)	Bolted connectors	Peikko	Peikko bolted connections provide fast and safe assemblies of precast concrete elements further improving the competitiveness of the precast concrete industry. HPKM Column Shoes, combined with HPM Anchor Bolts or COPRA Anchoring Couplers, are used to quickly create moment resisting column connections. Column shoes are cast into precast concrete columns, whereas anchor bolts are cast into foundations or other supporting structures. At construction sites, the columns are erected on the anchor bolts and adjusted to the desired position by tightening nuts onto the anchor bolts. After installation, the joint between the column and the foundation is grouted. At the final stage, the grouted joint acts as a traditional reinforced concrete section.	Slowing	Design for reversibility (e.g. modularity) Design for reuse Avoidance or reuse of (carbon-intensive) components and structural elements	Out	No	-	https://media.peikko.com/file/dl/i/YuEX4A/qI7Ijmh J1LIASRrEq_2DFQ/PeikkoWhitePaper_Boltedconnectionsforprecaststructuresenablingcircularitywithoutcompromisingperformance.pdf?fv=5474
7	Traditional	Steel	Flexbuild	Voestalpine Sadef	FlexBuild is a steel framing system that is assembled using fully reversible joints. The steel components are of course not renewable or biodegradable, but they are very robust and can be recycled to a high standard after use. The skeletal system was developed as a building kit. Thanks to bolted connections, it can therefore be completely disassembled. The installation is quite simple and goes quickly. Through prefabrication, the works on site can be optimized even further. The modules can be fitted with techniques or recesses. In combination with a dry finish, they easily form a layered whole. In principle, it is possible to dismantle parts of the structure separately, although this is never self-evident in the case of load-bearing components. The components themselves are more difficult to handle due to their size and weight.	Slowing	Design optimization Design for reversibility (e.g. modularity) Design for reuse Resource efficiency during construction Waste prevention/reduction during construction	In	Unknown	-	https://www.voestalpine.com/sadef/Marktsectoren/Bouw/FlexBuild

#	Category	Material category	Name	Producer	Description	Circular categories of principles	Possibilities for application in following circular strategies	Circular In/Out/ Both	Real world application (Y/N)	Applied projects	Source (all data retrieved from sources between 9.8.2023 – x.x.2023)
8	Hybrid	Steel/Wood Modular System	LLEXX	Hahbo	LLEXX is a modular building system with which building modules can be placed quickly. This is particularly interesting for the construction of temporary or even permanent classrooms or offices. The modules are composed of different materials. This is mainly wood, for the interior and exterior finish and for the floor structure. An external steel structure and steel fastening profiles consist of partly recycled steel and can be recycled to a high standard after use. The walls are filled with cellulose insulation, made from recycled newsprint. The construction is largely demountable and thus allows reuse in the first instance, especially of the steel structure, which has a long lifespan. Installation is relatively simple and, above all, very quick. This is mainly due to the prefabrication and mutual compatibility of the building components in the modular system. This does not mean that the components can also be combined or exchanged with components from another building system. It does allow the internal layout to be adapted to changing needs.	Slowing	Design optimization Design for reversibility (e.g. modularity) Avoidance or reuse of (carbon-intensive) components and structural elements Resource efficiency during construction Intensive use of space	Out	Yes	Various projects throughout Belgium	https://hahbo.be/bouwsystemen/
9	Hybrid	Steel/Wood structure	Modular steel/wood skeleton	Knoopwerk	Knoopwerk is a modular timber frame construction system that can be built quickly and reversibly on the basis of a steel node. The wooden beams consist of renewable raw materials. The steel connector is robust and easily handles complex construction knots. After the end of life of the wooden elements, you can continue to reuse the steel pieces. The connections can be made quickly, without extensive experience or specific fittings. Suitable for DIY builders. Disassembly also goes smoothly. Although the structural beams and columns will have some dimensions, they are relatively easy to handle. In principle, it is possible to dismantle individual elements separately for repair or replacement, although this is of course never self-evident within a load-bearing structure. In any case, it is possible to separate different building layers from the timber frame in order to enable a faster adjustment of, for example, the facade or plan layout.	Regenerating, Slowing	Design optimization Dematerialization and lightweight construction Design for reversibility (e.g. modularity) Design for reuse Materials with low embodied carbon Avoidance or reuse of (carbon-intensive) components and structural elements Resource efficiency during construction Waste prevention/reduction during construction Low-carbon construction equipment	Both	Unknown	-	https://www.knoopwerk.be/

#	Category	Material category	Name	Producer	Description	Circular categories of principles	Possibilities for application in following circular strategies	Circular In/Out/ Both	Real world application (Y/N)	Applied projects	Source (all data retrieved from sources between 9.8.2023 – x.x.2023)
10	Biodegradable	Wood structure	Structurez	Woodinc	Structurez is a timber frame construction system that can be easily assembled and dismantled by using steel connecting elements. While the wooden beams and columns consist entirely of renewable raw materials, the steel connections enjoy a long service life and potential for high-quality recycling. The connections, based on a Japanese technique, ensure dismantling. This is relatively fast and does not require any specific expertise or tools. Although the structural elements require some dimensions, they are relatively easy to handle. In principle, it is possible to dismantle individual columns and beams separately for repair or replacement, although this is of course never self-evident within a load-bearing structure. In any case, it is possible to separate different building layers from the timber frame in order to enable a faster adjustment of, for example, the facade or plan layout.	Regenerating, Slowing	Design optimization Dematerialization and lightweight construction Design for durability and long-life Design for easy maintenance and repair Design for reversibility (e.g. modularity) Design for reuse Materials with low embodied carbon Renewable and toxic-free materials Resource efficiency during construction Waste prevention/reduction during construction	Both	Yes	Various projects in Belgium	https://woodinc.be/mogelijkheden/villabouw/
11	Biodegradable	Wood structure (CLT)	Systimber	Systimber	Systimber is a structural system in which beams of cross-laminated timber or CLT are connected to a wooden solid construction via metal connecting pieces. The structure can be left exposed on one side, thus reducing the use of finishing materials. The wood is renewable, the metal pieces are very robust and can be recycled later. The system can be completely dismantled and is quick and easy to install. By connecting the components in series, it is not possible to remove one component independently of the others. By connecting slender beams to form load-bearing walls, the system is relatively manageable. The system can be used within a layered structure. In that case, interior walls are designed as non-load-bearing as possible and independent of the load-bearing structure.	Regenerating, Slowing	Design optimization Dematerialization and lightweight construction Design for reversibility (e.g. modularity) Materials with low embodied carbon Renewable and toxic-free materials Avoidance or reuse of (carbon-intensive) components and structural elements Resource efficiency during construction Waste prevention/reduction during construction	Both	Yes	Various projects in Belgium	https://www.systimber.com/werkwijze/

#	Category	Material category	Name	Producer	Description	Circular categories of principles	Possibilities for application in following circular strategies	Circular In/Out/ Both	Real world application (Y/N)	Applied projects	Source (all data retrieved from sources between 9.8.2023 – x.x.2023)
12	Biodegradable	Wood modular system	Blokiwood	Tymber Buildings	The Blokiwood system consists of wood modules that are prefabricated off-site and put together in 1-2 days on-site. After installation the building is wind- and watertight.	Regenerating	Design optimization Dematerialization and lightweight construction Materials with low embodied carbon Renewable and toxic-free materials Avoidance or reuse of (carbon-intensive) components and structural elements Resource efficiency during construction Waste prevention/reduction during construction Low-carbon construction equipment	In	Yes	Various projects in Belgium and The Netherlands	https://tymberbuildings.com/prefab-bouwen/
13	Biodegradable	Wood modular system	STEKO	Steko Holz-Bausysteme AG	STEKO is a logical modular building system based on latest technology allowing sustainable construction, which thereby meets the highest requirements regarding stability, earthquake safety, durability, comfort, and design flexibility. STEKO is a kit system, which opens new dimensions for the principal, the planners, and entrepreneurs. STEKO reduces the planning effort and increases the creative scope. The CAD-supported planning works with a simple basic framework, which allows huge design flexibilities due to fine increments – 16 cm horizontally and 8 cm vertically. Due to the new pushfit fitting the modules create a statically detectible unit and a massive, unmoveable combination in a wall.	Regenerating	Design optimization Dematerialization and lightweight construction Design for reversibility (e.g. modularity) Design for reuse Materials with low embodied carbon Renewable and toxic-free materials Avoidance or reuse of (carbon-intensive) components and structural elements Resource efficiency during construction Waste prevention/reduction during construction Low-carbon construction equipment	In	Yes	Various projects in Switzerland, Germany, and Italy	https://www.steko.ch/en/bausystem/steko-construction-system/

#	Category	Material category	Name	Producer	Description	Circular categories of principles	Possibilities for application in following circular strategies	Circular In/Out/ Both	Real world application (Y/N)	Applied projects	Source (all data retrieved from sources between 9.8.2023 – x.x.2023)
14	Biodegradable	Timber/Straw modular system	EcoCocon	EcoCocon	EcoCocon panels are made of 98% natural renewable materials. Making them as close to nature as possible results in high indoor air quality with no harmful substances emitted. The entire system is permeable to vapour – it allows excess humidity to escape – and with no thermal bridges and airtight, it leaves no space for draughts or mould. Natural materials create a healthy indoor microclimate with even temperatures – warm in winter and cool in summer.	Regenerating	Dematerialization and lightweight construction Materials with low embodied carbon Renewable and toxic-free materials Secondary materials and components Avoidance or reuse of (carbon-intensive) components and structural elements Resource efficiency during construction Waste prevention/reduction during construction	In	Yes	Various projects throughout Europe	https://ecococon.eu/
15	Biodegradable	Straw blocks	Straw bale building blocks	Woonder	A straw bale building consists of wood, straw, loam and lime. A timber frame provides the structure. Straw bales insulate the house in the exterior walls, roof and floor. Clay as an interior plaster and trass lime on the exterior wall of the house protect the bales and the house against weather influences. Plates, foils and extra processing of the bales usually make the building less efficient.	Regenerating	Dematerialization and lightweight construction Design for reuse Materials with low embodied carbon Renewable and toxic-free materials Avoidance or reuse of (carbon-intensive) components and structural elements	Both	Unknown	-	https://www.woonder.be/strobalen
16	Biodegradable	Rammed earth	Kastar	BC Materials	BC Materials produces clay products from excavated soil from city yards. Instead of being removed and dumped, the soil becomes raw material for high-quality building materials. Kastar is a mixture for rammed earth that can be used to make interior and exterior walls, but also floors. After drying, the rammed earth forms a monolithic whole. Although disassembly is therefore not possible, the loam itself can be reused after demolition. After all, by wetting them, you can rework unbaked clay and reuse it repeatedly for the production of other clay elements. As a dry mixture, the loam is easy to handle. Installation is relatively simple and fast. Just like a fair-faced concrete, the rammed earth can be left visible. This saves finishing material.	Regenerating, Closing	Design for reuse Materials with low embodied carbon Renewable and toxic-free materials Avoidance or reuse of (carbon-intensive) components and structural elements Low-carbon construction equipment	Both	Yes	Various projects in Belgium	https://bcmaterials.org/products/kastar

#	Category	Material category	Name	Producer	Description	Circular categories of principles	Possibilities for application in following circular strategies	Circular In/Out/ Both	Real world application (Y/N)	Applied projects	Source (all data retrieved from sources between 9.8.2023 – x.x.2023)
17	Biodegradable	Cork	Cork	Unknown	The Cork House is an entirely cork construction, with solid structural cork walls and roof. It has an exceptionally low carbon footprint during its whole life cycle. The house is designed for disassembly and can be constructed by hand.	Regenerating, Closing	Dematerialization and lightweight construction Design for reversibility Materials with low embodied carbon Renewable and non-toxic materials Avoidance of (carbon-intensive) components and structural elements Resource efficiency in construction Waste prevention/reduction during construction Low-carbon construction equipment Maintenance and repair with minimum resources	Both	Yes	Cork House (UK)	https://www.architecture.com/awards-and-competitionslanding-page/awards/riba-regional-awards/riba-southaward-winners/2019/cork-house
18	Biodegradable	Clay	Clay	Aalto University	The goal of the project is to create a light clay composite material that is suitable for the industrial production of building products, meets technical requirements and uses mainly circular economy flows as raw material. Lightweight clay has many good properties and it has been found to work in individual sites, but the utilization of clay on an industrial scale requires development work in terms of thermal insulation, workability and drying, among other things.	Regenerating, Closing	Design for reversibility (e.g. modularity) Materials with low embodied carbon Renewable and toxic-free materials Secondary materials and components Avoidance or reuse of (carbon-intensive) components and structural elements	Both	No	-	https://www.aalto.fi/fi/uutiset/vahahiilinen-kevytsavi-auttaa-pienentamaan-rakentamisen-jatemaaraa-ja-hiilijalanjalkea

Skin

#	Category	Material category	Name	Producer	Description	Circular categories of principles	Possibilities for application in following circular strategies	Circular In/Out/ Both	Real world application (Y/N)	Applied projects	Source
1	Traditional	Brick	Façade tiles	Wienerberger	Thanks to their dry installation, roof tiles are very suitable for reuse. As facade cladding, they are a suitable alternative to non-reversible systems. The tile tiles consist of natural materials and are completely healthy and safe to install. In addition, they have a long service life and can be easily reused. After all, the quick and easy installation is completely reversible. It is also easy to remove or replace just one or a few tiles independently of the rest of the facade. With their limited dimensions, they are manageable and easy to store. Finally, as facade cladding, the tiles enable a layered structure, which can also seamlessly connect to the roof structure.	Slowing	Design for durability and long-life Design for easy maintenance and repair Design for reversibility (e.g., modularity) Maintenance and repair with minimum resources	Out	Yes	Various projects in Belgium	https://www.wienerberger.be/gevel/systemen/gevelbekleding-kleidakpannen.html
2	Traditional	Brick	Reused bricks	Franck	Franck recovers old facing bricks during demolition works. They are suitable for reuse and save on the production of new materials and products. Moreover, they give a building project a historical character. The bricks are easy and relatively quick to install. By using a weak mortar, they can be recovered in future demolition works. However, that takes a lot of time. It is not possible to recover the stones with a cement mortar. The stones are manageable and robust. They have already proven their longevity. They cannot be placed independently in a masonry bond. As a facade finish, they do form part of a layered building solution.	Slowing, Closing	Design for durability and long-life Secondary materials and components	Both	Yes	Various projects in Belgium	https://www.franck.be/gevelstenen
3	Traditional	Brick	Facadeclick, Clickbrick	SBS Belgium, Wienerberger	Traditional clay bricks, that are modified in such a way that they can be stacked in a dry manner without mortar (might be a need for supporting materials depending on the solution).	Slowing	Design optimization Design for reversibility (e.g. modularity)	Out	Yes	Several projects in Belgium & The Netherlands	http://www.facadeclick.be/, https://www.architectum.com/sustainable-solutions/one-material-with-many-lives.html
4	Hybrid	Concrete & Wood	Sandwich element	Heidelberg Contiga & Metsä Wood	The collaboration involves starting the development of a new hybrid element that is constructed with both concrete and wood as constituent building material. The result when combining climate-improved concrete with wood, is a new type of building element with high strength and durability as well as lower weight and carbon footprint. The hybrid element will have an estimated 70 percent lower climate impact. The hybrid element is a so-called sandwich element that will be well suited to facade walls with high resistance to weather and wind. It is constructed with Metsä Wood's Kerto LVL Q-panel as a load-bearing core panel and with an external panel of Heidelberg Materials climate-improved concrete.	Slowing	Avoidance or reuse of (carbon-intensive) components and structural elements	In	No	-	https://www.metsagroup.com/metsawood/news-and-publications/news/2023/concrete-manufacturer-heidelberg-materials-precast-contiga-and-metsa-wood-develop-new-hybrid-element/

#	Category	Material category	Name	Producer	Description	Circular categories of principles	Possibilities for application in following circular strategies	Circular In/Out/ Both	Real world application (Y/N)	Applied projects	Source
5	Traditional	Steel	Light Steel Framing Façade	Jansen by ODS	Jansen by ODS, also known as Kloeckner Metals Belgium, combines the lightweight steel construction system Skellet with the curtain wall system Jansen Viss into a fully demountable facade construction. With its steel components, the system guarantees a long service life and allows high-quality recycling. In the first place, however, the system has been developed for reuse. After all, all connections are reversible. Assembly and disassembly are also relatively quick and easy. Components are usually difficult to handle due to their large dimensions. It is possible to disassemble and replace certain components separately. To make reuse practically possible, Jansen by ODS experimented with material passports. In addition, it makes second-hand components available for reuse on the basis of so-called harvest cards.	Slowing	Design optimization Design for reversibility (e.g. modularity) Design for reuse Resource efficiency during construction Waste prevention/reduction during construction	Out	Yes	Several projects in The Netherlands and Belgium	https://www.c-bouwers.be/index.php/producten/light-steel-framing-facade
6	Traditional	Ceramic (roofing)	Reused roof tiles	Franck	Franck recovers old roof tiles during demolition works. They are suitable for reuse and save on the production of new materials and products. Moreover, they give a building project a historical character. Roof tiles are easy and quick to install. They are a time-honored example of reversible roofing and can be easily dismantled and reused. In addition, they can be removed or replaced independently of each other. They are manageable and robust. They have already proven their longevity. After all, as a roof finish, they are part of a layered building solution.	Slowing, Closing	Design for durability and long-life Secondary materials and components Maintenance and repair with minimum resources	Both	Yes	Various projects in Belgium	https://www.franck.be/dakpannen
7	Hybrid	Bitumen (roofing)	Derbitumen	Derbigum	Derbitumen consists of a minimum amount of recycled bitumen material that is used as a resource to create Derbitumen. Derbitumen itself is again 100% recyclable at the end of its lifetime.	Slowing, Closing	Design for durability and long-life Design for reuse Secondary materials and components	Both	Yes	Various projects throughout Europe	https://derbigum.be/nl/waterdichting/circulair-dak/
8	Innovative	Rockpanel (façade cladding)	Rockpanel	Rockwool	With Rockpanel, ROCKWOOL offers rock wool facade panels. Basalt, the mineral raw material they use for this, is not renewable but can be recycled to a high standard. The panels therefore partly consist of recyclate and can be almost completely recycled into new construction products after use. To facilitate that process, ROCKWOOL offers the Rockcycle service, which collects residual flows of rock wool products. In the first place, however, the facade panels offer many possibilities for reuse. After all, it is easily possible to mount them via reversible connections. This is done quickly and easily. The panels have a long life and, depending on the dimensions, are easy to handle. In contrast to many other facade finishes, it is also possible to remove or replace the panels independently of each other. After all, they enable a layered facade construction.	Slowing, Closing	Design for durability and long-life Design for reversibility (e.g. modularity) Design for reuse Secondary materials and components	Out	Yes	Various projects throughout Europe	https://www.rockpanel.be/

#	Category	Material category	Name	Producer	Description	Circular categories of principles	Possibilities for application in following circular strategies	Circular In/Out/ Both	Real world application (Y/N)	Applied projects	Source
9	Traditional	Cement-fiber (façade cladding)	Eternit	Equitone	The panels are thin and lightweight. They can be cut to fit virtually any type of building facade, with a minimum amount of material per square meter. They are made of water, portland cement, cellulose, and natural minerals. They are recyclable. The facade materials are designed as a modular system – easy to apply, remove, modify or dismantle for recycling.	Slowing	Dematerialization and lightweight construction Design for durability and long-life Design for easy maintenance and repair Design for reversibility (e.g. modularity) Design for reuse Waste prevention/reduction during construction	Out	Yes	Various projects throughout Europe	https://www.equitone.com/nl-be/
10	Innovative	Glass Foam Granulate (Thermal Insulation)	Geocell	Eurabo	Geocell is a glass foam granulate that is extracted from residual glass. In this way, it directly confronts waste. Glass foam can be recycled after use. In the form of granulate, it is mainly used as a moisture-resistant and draining filling layer and as floor insulation. It is poured dry and can easily be removed again. Moreover, installation is simple and relatively quick. The granulate is quite fine and therefore compatible with different floor thicknesses and floor plans, even in irregular spaces and with imperfections. It is also easy to handle and allows parts of a poured layer to be removed independently of the whole.	Closing	Design for reuse Secondary materials and components	Both	Yes	Various projects around Europe	https://www.eurabo.be/nl/producten/geocell-glasschuim-granulaat
11	Innovative	Cellulose (Thermal insulation)	iQ3-cellulose, Isocell	Isoproc, Isocell	The cellulose is locally produced from recycled newsprint. This is not only a waste product, but also comes from a renewable raw material source. This minimizes the impact on human health and the environment. This was calculated through a life cycle analysis and bundled in a so-called EPD. Cellulose owes its very low environmental impact to its production and material composition. Because it is blown in dry, it can also be easily removed again. This is quick and easy but will usually not lead to reuse. The flakes are very light and easy to handle. Finally, within different parts of the facade, they can be removed independently, for example to provide new facade openings.	Slowing, Closing	Design for reversibility (e.g. modularity) Materials with low embodied carbon Renewable and toxic-free materials	Both	Yes	Various projects in Belgium	https://www.isoproc.be/nl/solutions/producten/iQ3-cellulose/22, https://www.isocell.com/de-at/

#	Category	Material category	Name	Producer	Description	Circular categories of principles	Possibilities for application in following circular strategies	Circular In/Out/ Both	Real world application (Y/N)	Applied projects	Source
12	Biodegradable	Cork (Thermal insulation)	RecYcork	De Vlaspit	RecyCork is a recycled cork granulate that is used as loose insulation. It is produced within the social employment project De Vlaspit. Through a series of collection points, they collect discarded cork such as wine stoppers and process it into a granulate. This is extremely suitable as insulation material for floors, walls and other cavities. By using a fine and loose granulate, the insulation can be installed completely reversibly. This also happens quickly and is simple. The granulate is also very manageable. The insulation thickness is easy to adjust and thus compatible with different wall or floor constructions. They can be layered. Finally, it is in principle possible to remove the granulate locally and independently, for example to create additional floor or wall openings.	Slowing, Closing	Design for reversibility (e.g. modularity) Materials with low embodied carbon Renewable and toxic-free materials	Both	Yes	Various projects in Belgium	https://www.recycork.be/
13	Innovative	Grass (Thermal insulation)	Gramitherm	Gramitherm	The Gramitherm process extracts from raw grass cellulose fibres (used to produce Gramitherm). The juices that are also extracted are supplied to biogas units as an energy booster. The Gramitherm process secures a full utilisation of all grass components and generates high efficiency and added value to the raw material. The cutting and harvesting of “waste” grass; 1 acre of land will allow to produce 200 M3 of insulating products.	Closing	Materials with low embodied carbon Renewable and toxic-free materials	In	Yes	Various projects throughout Europe	https://gramitherm.eu/?lang=en
14	Innovative	Cotton (Thermal insulation)	Metisse, Pavatextil P	Le Relais, Soprema	Bio-sourced insulation, made from recycled cotton, it is an innovative recycling solution for cotton textiles collected that cannot be reused as they are, and which would otherwise be destined for incineration. It also gives a second life to a quality raw material – cotton – whose insulating properties are well established.	Closing	Secondary materials and components	In	Yes	Various projects in France and Belgium	http://www.isolantmetisse.com/, https://www.soprema.be/nl/product/isolatie/katoen/pavatextil-p
15	Biodegradable	Lime hemp (Thermal insulation)	Lime Hemp	Woonder	Lime hemp can be used to build sturdy walls that insulate well. In combination with vapor-permeable finishing materials on the inside and outside, the result is a 'breathing' and moisture-resistant wall construction with a favorable CO_2 balance and good hygrothermal properties. Hemp provides insulating reinforcement, lime is the binder. A 100% natural additive for homogeneous mixing is added for better adhesive strength and a faster curing process. Lime hemp also optimizes the moisture balance in the wall and the indoor air of your building. the walls act like a skin. In one simple monolithic bonded layer.	Regenerating	Materials with low embodied carbon Renewable and toxic-free materials	Both	Yes	Various projects in Belgium	https://www.woonder.be/kalkhennep

#	Category	Material category	Name	Producer	Description	Circular categories of principles	Possibilities for application in following circular strategies	Circular In/Out/ Both	Real world application (Y/N)	Applied projects	Source
16	Biodegradable	Wood-fiber (Thermal insulation)	Pavaflex Plus	Soprema	Pavaflex Plus is a flexible wood fiber insulation, suitable for floors, walls and roofs. The wood fiber insulation is made from waste streams of wood chips from sawmills. In addition to being recycled, the material is therefore renewable, but it can also be recycled again at a high quality after use. In the right conditions, the material is even biodegradable. In principle, reuse is also possible. The flexible mats are placed in a dry way. That is simple and allows you to easily remove them again, independently of each other. Their low weight also makes them relatively easy to handle.	Slowing, Closing, Regenerating	Design for reversibility (e.g. modularity) Design for reuse Materials with low embodied carbon Renewable and toxic-free materials Secondary materials and components	Both	Yes	Various projects throughout Europe	https://www.soprema.be/nl/product/isolatie/houtvezel/platen/pavaflex

Services

#	Category	Material category	Name	Producer	Description	Circular categories of principles	Possibilities for application in following circular strategies	Circular In/Out/ Both	Real world application (Y/N)	Applied projects	Source
1	Traditional	Services Module	SAM	BAO Living	The Smart Adaptive Module or SAM is an integrated utility modular system. Bathroom, kitchen and associated pipes, but also heating, ventilation and electricity can be brought together. Thanks to this centralization and the prefabrication of the modules, techniques can be installed quickly. Bringing all utilities together also makes it easier to organize the remaining space within a free plan. Moreover, the techniques remain accessible for maintenance and replacement and to make adjustments to the capacity or configuration of the modules. Within the modular building system, various elements are always compatible with each other. This does not mean that they can be automatically combined or exchanged with other systems or building elements. Individual components within the system can be removed, modified or replaced to a certain extent independently of each other.	Slowing	Design optimization Design for easy maintenance and repair Design for reversibility (e.g. modularity) Design for reuse Waste prevention/reduction during construction Maintenance and repair with minimum resources	Out	Yes	Various projects in Belgium and The Netherlands	https://www.baoliving.com/
2	Innovative	Technical unit	Litobox	Lito	This box combines all technical appliances in a compact unit that can be placed both inside, but preferably outside of homes. All heating, cooling, electricity & heat generation and/or ventilation are included in the unit. By its location outside it can be quickly installed and moved to other locations.	Slowing	Design optimization Design for durability and long-life Design for easy maintenance and repair Design for reversibility (e.g. modularity) Design for reuse Improve operational efficiency (e.g. energy use)	Out	Yes	Yes, various projects in Belgium	https://lito.be/en/products
3	Innovative	Appliances	Hydraloop	Ecopuur	The Hydraloop is an automatic water purification installation that makes it possible to recycle gray water. You circulate domestic water and use it after purification for the toilet, washing machine or garden. The device itself can be installed reversibly. You can easily connect it to the pipe network. These pipes must be provided for the installation. It is easier to integrate the installation of a Hydraloop in a (re)construction project, but there are also possibilities without it. As a plug-and-play installation, the appliance can be removed, repaired or replaced independently of the pipes. In principle, it forms a layered solution, although it is also important to consider the independence and accessibility of the supply and discharge pipes. The Hydraloop is self-cleaning and therefore requires little maintenance. If necessary, you can also rely on Ecopuur after installation.	Narrowing	Design for reversibility (e.g. modularity) Maintenance and repair with minimum resources Improve operational efficiency (e.g. energy use)	Out	Yes	Various projects in Belgium	https://www.ecopuur.be/energietechnieken/water/waterrecyclage

#	Category	Material category	Name	Producer	Description	Circular categories of principles	Possibilities for application in following circular strategies	Circular In/Out/ Both	Real world application (Y/N)	Applied projects	Source
4	Hybrid	Loam ceiling heating	Lehm-Module	Agrillatherm	The water-based heating and cooling ceiling from ArgillaTherm combines the advantages of innovative cooling technology and heating technology with the positive properties of loam as a building material and relies on a newly developed, globally unique and patented, open modular construction system. Production of the clay climate system almost CO2-neutral. 100% return to nature possible. Cradle to Cradle.	Regenerating	Design for reversibility (e.g. modularity) Materials with low embodied carbon Renewable and toxic-free materials Improve operational efficiency (e.g. energy use)	Out	Yes	Various projects in Belgium and Germany	https://argillatherm.de/
5	Hybrid	Dry system floor heating	Rautherm	Rehau	With dry construction, the underfloor heating installation system is not finished with a wet screed after installation. A finishing floor can be laid directly over this. With a dry installation system you use conductive plates that distribute the heat. Dry installation is popular when you are dealing with a wooden subfloor, this is often the case with renovation projects.	Slowing	Design for reversibility (e.g. modularity) Design for reuse	Out	Yes	Various projects throughout Europe	https://www.rehau.com/nl-nl/installatie-bouwbedrijf/gebouwentechniek/vloerverwarming-koeling/verwarmen-en-koelen-in-de-woningbouw
6	Traditional	Underfloor cable systems	Soluflex, Daltecnic	LeGrand, Daltecnic	Modular raised floor modules allow for the electrical components to be placed underneath. These are always reachable afterwards and it is possible to redesign the electrical layout and take the raised floor away again at the end of the building's lifetime. Thanks to its modular system, re-use is fairly simple.	Slowing	Design for durability and long-life Design for easy maintenance and repair Design for reversibility (e.g. modularity) Design for reuse	Out	Yes	Various projects throughout Europe	https://www.slideshare.net/DirkMostien/pres-en-daltecnic, https://www.legrand.be/nl/oplossingen/energiedistributie

Space plan

#	Category	Material category	Name	Producer	Description	Circular categories of principles	Possibilities for application in following circular strategies	Circular In/Out/ Both	Real world application (Y/N)	Applied projects	Source
1	Hybrid	Inner walls (system)	Partition walls	JuuNoo	The JuuNoo interior wall system consists of light metal profiles that are adjustable in height and angle. They are stretched between floor and ceiling and attached with Velcro. The system is not only quick and easy to install but can also be easily dismantled thanks to the reversible connections. Because they are adaptable, the profiles lend themselves very well to use and reuse in different situations and they are easier to apply within different size systems. They are also quite easy to handle and have a long service life. The inner wall system can be filled with insulation and finished with different sheet materials. By using a reversible Velcro connection there too, all layers remain maximally accessible. These characteristics make JuuNoo suitable for reuse and closing the technical cycle. Thanks to a buy-back guarantee, this system also offers a financial advantage in the long term.	Slowing	Design optimization Design for durability and long-life Design for easy maintenance and repair Design for reversibility (e.g. modularity) Design for reuse Resource efficiency during construction Waste prevention/reduction during construction Maintenance and repair with minimum resources	Out	Yes	Various projects in Belgium	https://www.juunoo.com/
2	Hybrid	Inner walls (system)	Circowall MOD	Circomat	MOD is a non-load-bearing interior wall system consisting of modular wooden frames. They can be linked together in different configurations and finished with different sheet materials. The finishes mainly consist of natural, renewable or even biodegradable materials such as wood, mycelium, cellulose or clay. The wood of the frames is renewable, but they are primarily intended for reuse. They are therefore bolted together completely reversibly, the finish is attached via simple hooks. That is fast and very easy. The chosen module size of half a meter guarantees mutual compatibility. By following this with the finishing, many possibilities for adjustments and reorganizations arise. The system also allows connections to interior elements such as cupboards. However, within large applications it is not always possible to separate individual components independently from the whole. Circomat finally offers the Circowall MOD within a circular business model, with a buy-back guarantee, for rent or as a service.	Slowing	Design optimization Design for easy maintenance and repair Design for reversibility (e.g. modularity) Design for reuse Materials with low embodied carbon Renewable and toxic-free materials Waste prevention/reduction during construction Maintenance and repair with minimum resources	Out	No	-	https://circowalls.myportfolio.com/circowall-mod-gallery

#	Category	Material category	Name	Producer	Description	Circular categories of principles	Possibilities for application in following circular strategies	Circular In/Out/ Both	Real world application (Y/N)	Applied projects	Source
3	Biodegradable	Inner walls (loam)	Brickette	BC Materials	BC Materials produces clay products from excavated soil from city yards. Instead of being removed and dumped, the soil becomes raw material for high-quality building materials. Brickette is a pressed clay brick for non-load-bearing interior walls. It is mortared with a clay mortar. The loam can be recovered in its entirety after decomposition. A mortar connection cannot be dismantled and cannot be reversed very quickly or easily. It will therefore be difficult to reuse the stones directly, but the loam can. After all, by wetting them, you can rework unbaked clay and reuse it repeatedly to produce other clay elements. The dimensions of the bricks themselves are compatible with those of traditional bricks. The bricks are therefore easy to handle and can be placed easily and relatively quickly.	Regenerating, Closing	Design for reuse Secondary materials and components	Both	Yes	Fort V, Belgium	https://bcmaterials.org/products/brickette
4	Biodegradable	Inner walls (hemp)	-	IsoHemp	The hemp blocks from Isohemp consist of a pressed lime hemp mixture. They are suitable as insulation material or for non-load-bearing walls. Lime and certainly hemp are renewable materials. Under the right conditions, the blocks can be biodegraded. The raw materials are available locally, very little energy is used during production and water is recycled. A life cycle analysis bundles the results regarding the resulting low environmental impact. While the hemp blocks make a strong contribution to closing the biological cycle, they create fewer opportunities for reuse within the technical cycle. After all, the blocks cannot be dismantled with an adhesive connection. Yet they can be installed quickly and relatively easily. They are manageable and available in different thicknesses and sizes.	Regenerating	Materials with low embodied carbon Renewable and toxic-free materials	In	Yes	Various projects in Belgium	https://www.isohemp.com/nl/hennepblokken-voor-natuurlijke-bouwwerken
5	Biodegradable	Wall finish (Loam stucco)	Brusseleir	BC Materials	BC Materials produces clay products from excavated soil from city yards. Instead of being removed and dumped, the soil becomes raw material for high-quality building materials. Brusseleir is a clay plaster. This can be further finished as a basic plaster with a paint or decorative plaster or kept as a finishing plaster. A plaster is of course not reversible in the literal sense of the word. Nevertheless, the loam can be reused after decomposition. After all, by wetting them, you can rework unbaked clay and reuse it repeatedly to produce other clay elements. Naturally, it must then be possible to separate the loam from other residual fractions during the demolition process. The plaster mixture itself is easy to handle and can be applied easily and relatively quickly.	Regenerating, Closing	Materials with low embodied carbon Renewable and toxic-free materials	Both	Yes	Various projects in Belgium	https://bcmaterials.org/products/brusseleir

#	Category	Material category	Name	Producer	Description	Circular categories of principles	Possibilities for application in following circular strategies	Circular In/Out/ Both	Real world application (Y/N)	Applied projects	Source
6	Innovative	Acoustic panels	Pan-terre	Acoustix	Acoustix Pan-terre panels are 16 mm thick rigid panels. The panels respect the environment: 100% from recycling and 100% recyclable; mixture of recycled paper and flax shives; Materials derived from cellulose.	Closing	Materials with low embodied carbon Secondary materials and components	Both	Yes	Various projects in Belgium	https://www.acoustix.be/nl/akoestische-isolatie/acoustix-panterre
7	Traditional	Ceiling solutions	Rockfon	Rockwool	After installation, the cutting waste of the panels is collected for recycling. And when the suspension systems and acoustic ceiling solutions have reached the end of their lifespan, those are recycled too. Those products are then transformed into new, sustainable solutions with the same quality. In addition, the products are never downcycled into lower value products.	Slowing	Design for reuse Secondary materials and components Waste prevention/reduction during construction	Out	Yes	Various projects throughout Europe	https://www.rockfon.be/
8	Innovative	Flooring (system)	Staenisgrid	Staenis	The Staenis slat is a modular screed slat with which dry floors can easily be built. The system consists of plastic rods that are placed in a grid via adjustable feet. By cutting some components, the system easily adapts to irregular spaces. However, a certain amount of waste is difficult to avoid. The plastic used is not renewable or degradable but can be recycled. The system itself is completely demountable. The entire floor construction is of course only possible when a dry finish and filling is used, such as sand, cork, shells, lime hemp or glass foam granulate. The grid is very quick and easy to install and well suited for self-builders. The components are easy to handle and can be removed or replaced independently of each other within the grille without much effort. Finally, the system separates the load bearing from the insulating function and techniques within the dry construction can be processed in an accessible manner.	Slowing	Design for reversibility (e.g. modularity)	Out	Yes	Various projects throughout Europe	https://www.staenis.com/nl-BE
9	Traditional	Flooring textiles	Various	Tarkett	(Reused) Carpet tiles, PV flooring and Linoleum solutions by various producers.	Slowing, Closing	Design for reuse Secondary materials and components	Both	Yes	Established solutions that are presented in various projects around the world	https://www.tarkett-group.com/en/climate-circular-economy/circular-economy/#recycling

Stuff

#	Category	Material category	Name	Producer	Description	Circular categories of principles	Possibilities for application in following circular strategies	Circular In/Out/ Both	Real world application (Y/N)	Applied projects	Source
1	Traditional	Outdoor tiling	Right Wae	Studio Wae	Old tiles are processed into different fractions. A small proportion of new sand, dye and non-circular cement is added. Normally, the material is broken up and used under asphalt roads. In cooperation with our processor it is broken into finer fractions, sieved, and removed from impurities. In the new tiles, 76% by weight of raw materials are now replaced by this fraction. The raw materials of The Right Wae tiles also remain in the circular loop, because at the end of the lifetime, these raw materials can also be fully processed again into raw materials to form new circular pavement.	Closing	Design for reuse Secondary materials and components	Both	Yes	Various projects in The Netherlands	https://www.c-bouwers.be/producten/right-wae
2	Traditional	Furniture	Circular furniture	Gispen	Gispen enables raw materials and products reuse as much as possible and with that prevents waste. Gispen works according to 5 principles: Clients with constant needs operate as long as possible with existing furniture. For the implementation of new needs materials that are already in circulation are being used. New products are tested against the Design Framework, which is a circular yardstick ensuring sustainable design. To close the loop, products, components, and materials are moved into a next phase of use. Hereby, the environmental impacts are considered on several levels. To enable the continuity of the circular system Gispen works for people, planet and profit.	Slowing, Closing	Design optimization Design for durability and long-life Design for easy maintenance and repair Design for reversibility (e.g. modularity) Design for reuse Secondary materials and components Maintenance and repair with minimum resources Minimize waste	Both	Yes		https://www.gispen.com/en/circular-interior-design/
3	Traditional	Floor decoration	Circular rugs	Studio Wae	These rugs with geometrical shapes, are made of 100% production waste from well-known carpet producers in the Netherlands. Collaboration contracts have been signed with these companies to prolong the lifespan of their waste. Choose any color, shape, and size to create a unique rug that fits any space. The M.C. Escher-inspired shapes and unique clicking system, providing complete freedom to create any design.	Closing	Design for reuse Secondary materials and components	Both	Yes	Various projects in The Netherlands	https://www.c-bouwers.be/producten/modulaire-vloerkleden

Appendix C – Ongoing and completed R&D-projects

The primary input for the table has come from Kiertotaloushankkeet (2023), supplemented with input that originated from the author's network and knowledge. The input has been qualitatively reviewed.

Ongoing R&D-Projects

#	Project	Year(s)	Type	Topics	In/Out/Both	Layers	Partners	Expected Outcomes
1	CEGO	2021-2023	Research, Education	Supporting SME entrepreneur's CE business skills through training, seminars, and coaching	Both	Management	KEUKE, Laurea, Novago, Posintra	Speeding up the realization of the business potential of the circular economy and the construction of a Uusimaa-wide circular economy ecosystem
2	CIRCuIT	2019-2023	Research	Developing operational models that enable cities to implement circular economy solutions for construction in urban planning and strive to include them as part of their current operations.	Both	Management	HSY, PK-Seudun Kierrätyskeskus Oy, TAU, Vantaan Kaupunki, and EU-partners	Several SotA's, Guides, and Instructions
3	CityLoops	2019-2023	Applied Research	Provide a tested for CE C&DW, and a CE promotion model that other local and regional governments across Europe can follow.	Out	Management, All	XAMK, Miksei Mikkeli Oy	Demonstrations of possibilities from a circularly demolished hospital and healthcare centre
4	ICEBERG	2020-2024	Research	The project develops and tests innovative solutions for recycling construction waste. The trial includes e.g. new innovative ways to recycle wood waste. The goal of VTT and the companies is to develop and demonstrate new cost-effective solutions for the recovery and high-quality recycling of waste generated in construction and demolition activities.	In	Structure, Skin	Purkupiha Group Oy, VTT, and EU-partners	New cost-effective solutions for the recovery and high-quality recycling of (wood) waste generated in construction and demolition activities. In addition, VTT is involved in developing tools based on RFID technology for an electronic material passport.
5	KERPUR	2021-2023	Research	To define quality criteria for recycling and to identify new uses for ceramic waste. The recycling of ceramic waste is being piloted together with companies	Both	Management, Structure, Skin	Åbo Akademi, SYKE, Turku Science Park Oy, Turun AMK	Research, Piloting, and Evaluating possibilities for ceramic waste
6	UUMA4	2021-2023	Applied Research	Environmental permit issues for new construction, greenhouse gas emissions and indicators, technical requirements for materials, consideration of the network, recycled growing media, low-carbon prefabricated construction, new binders for deep stabilization and stabilized excavated soils, and development of procurement process and criteria.	In	Management	Hankeosapuol1, Motiva, Ramboll	Various publications concerning projects done by Ramboll
7	Rapurc	2020-2023	Research	Development of circular economy operating models for construction and demolition	Both	Management	XAMK, Miksei Mikkeli	Business models for construction & CDW-companies
8	ReCreate	2021-2025	Applied Research	Investigates how used concrete elements could be removed intact and used as part of new buildings - as a profitable business	Both	Structure	Consolis Parma, Liike Arkkitehtistudio Oy, Ramboll, Skanska Kodit, Tampereen Kaupunki, TAU, Umacon, and EU-partners	Solutions for profitable re-use of concrete elements

#	Project	Year(s)	Type	Topics	In/Out/Both	Layers	Partners	Expected Outcomes
9	FCBRE	2018-2023	Applied Research	This project aims to increase by +50%, the amount of reclaimed building elements being circulated on its territory by 2032. NW-Europe houses thousands of SMEs specialized in the reclamation and supply of reusable building elements. Despite their obvious potential for the circular economy, these operators face significant challenges: visibility, access to important projects and integration in contemporary building practices. Today, the flow of recirculated goods stagnate and may even decrease due to a lack of structured efforts.	Both	Management, All	Rotor, Buildwise, Bellastock, Brussels Environment, City of Utrecht, Delft University of Technology, Embuild, Luxembourg Institute of Science and Technology, University of Brighton, Salvo Ltd, Scientific and Technical Center for Building.	Directory of companies, Specification methods, Reclamation audit method, Truly reclaimed label, Catalogue of elements, 37 pilot projects.

Completed R&D-Projects

#	Project	Year(s)	Type	Topics	In/Out/ Both	Layers	Partners	Outcomes
1	Build4Clima	2020-2021	Research	Defining common goal and state of vision	Both	Management	TAU, VTT	RDI roadmap for carbon neutral buildings
2	CirVol	2018-2022	Research	CircVol projects seek new solutions for the utilization of earth masses and large-volume side flows of industry in infrastructure and land construction.	Both	Site	Åbo Akademi, Geologian Tutkimuskeskus GTK, SYKE, Turku Science Park Oy, Turun AMK	Different opportunity maps and instructions
3	HYPPY	2019-2022	Research	Developing operating models for the participating municipalities through concrete experiments aimed at a better circulation of construction parts and materials from demolition waste, which enable new circular economy activities.	Unknown	Unknown	Green Net Finland, Hämeen AMK, Metropolia, Sykli	Unknown
4	CIRCWASTE	2016-2022	Research	Seven-year project that promotes the efficient use of material flows, the prevention of waste generation and the recycling of materials. The goal is to pilot Finland towards a circular economy and implement a national waste plan.	Both	Management	Business Joensuu, GS1 Finland Oy, Jyväskylän Kaupunki, Karelia AMK, Kemin Digipolis Oy, Keski-Suomen Liitto, Keski-Suomen Sairaanhoitopiiri, Kiertomaa Oy, Kompotek Oy, Lappeenrannan Kaupunki, Lappeenrannan Teknillinen Yliopisto, Pikes Oy, Pirkanmaan liitto, Pohjois-Karjalan Liitto, Porin Kaupunki, Puhas Oy, Ramboll Finland Oy, SYKE, Turun AMK, Varsinais Suomen Liitto	Different regional roadmaps for each participating region
5	KIEPPI	2019-2021	Research	Partnership model for sustainable neighborhoods	Both	Management	Espoon Kaupunki, Tampereen Kaupunki, Turku Science Park Oy	The end result of the project is the partnership model of a carbon-neutral district, where the various material flows needed by the growth of cities circulate in the regional economy as closed and resource-wise as possible.
6	Purater	2020-2021	Research	The suitability of demolition materials for different uses from the point of view of safety and health	Both	Management	Hämeen AMK, Laurea, Ramboll, Työterveyslaitos	Definition of boundary conditions for the material utilization of key construction waste fractions and building parts from the point of view of both purpose of use and safety and health.

#	Project	Year(s)	Type	Topics	In/Out/ Both	Layers	Partners	Outcomes
7	Kiertotalousliiketoimintaa vauhdittava alustaratkaisu	2020-2021	Development	Platform solution that accelerates circular economy business	Both	Management	Clic Innovation Oy, Motiva, Platform of Trust	Development of a data platform and marketplace aimed at the construction and demolition industry (Note: Platform not available (yet))
8	Wool2Loop	2019-2022	Applied Research	Reuse of mineral wool waste from the construction industry using geopolymer technology	Both	Skin	Oulun Yliopisto, Saint-Gobain Finland, Timegate Instruments Oy, and EU-partners	In the project, mineral wool is returned to circulation with the help of geopolymer technology. In this way, mineral wool can be used as a raw material replacing cement for new construction industry products.
9	RAPA	2020-2021	Applied Research	The main goal of the project is to develop new processing methods to increase the value chains of construction and demolition waste and to manufacture new products. The aim is to develop new products with a higher added value from waste fractions, which are in demand on the market. This would also increase birthplace sorting.	In	Unknown	LAB AMK	Unknown
10	BAMB	2015-2019	Applied Research	The goal of BAMB is to enable a systemic shift where dynamically and flexibly designed buildings can be incorporated into a circular economy. Through design and circular value chains, materials in buildings sustain their value – in a sector producing less waste and using less virgin resources. Instead of being to-be waste, buildings will function as banks of valuable materials – slowing down the usage of resources to a rate that meets the capacity of the planet.	Both	Management, All	Brussels Environment, BAM International, BRE UK, EPEA, Drees&Sommer, IBM, Ronneby Kommun, Sarajevo Green Design Foundation, SundaHus, Technische Universität München, Universiteit Twente, Universidade do Minho, VITO, Vrije Universiteit Brussel, Zuyd Hogeschool	The project has developed and integrated tools that will enable the shift: Materials Passports and Reversible Building Design – supported by new business models, policy propositions and management and decision-making models. During the project these new approaches have been demonstrated and refined with input from 6 pilots.
11	Super Circular Estate Project	2017-2021	Applied Research	The Super Circular Estate project will test new circular economy processes aimed at 100% reusing, repairing and recycling of the materials acquired from the demolition of an outdated social housing building. The project will experiment with and evaluate innovative reuse techniques for decomposing a high-rise tunnel formwork concrete building in Kerkrade. The demolition materials will be used to build 4 pilot housing units with 5 different reuse/recycle techniques to be compared in order to assess their viability and replicability.	Both	Management, All	Municipality of Kerkrade, Brunssum municipality, Landgraaf municipality, Stadsregio Parkstad Limburg, VolkerWessels Construction, Real Estate Development South and Dusseldorp Infra, Water Board Company Limburg, Limburg Drinking Water Company, IBA Parkstad B.V, Zuyd University of Applied Sciences, HeemWonen, Association of Demolition Contractors (VERAS	SCE consortium has tested and measured the environmental and economic impact of nine different circular construction techniques developed during construction of three SCE houses. Nine circular building techniques have been applied on three building functions: insulating, loadbearing and enclosing. For each of the mentioned building functions, one of circular methods of construction different reuse and recycling scenario have been tested from a donor building, such as: (1) direct reuse, (2) remanufacturing or (3) upcycling. Their economic and environmental impacts have been compared with conventional methods of construction in order to get first insides into the future potential and financial feasibility of innovative solution

Appendix D - Realized Building Pilots

The input in the table has (1) been qualitatively reviewed and the author has (2) added any missing data in columns E-J. All data added and/or modified by the author after review are marked in *Italics*. The following needs to be noted regarding the data in specific columns of the table:

- Column C: The terms 'StructureMA', 'StructureSY', 'Flexibility', 'Principle 1', and 'Principle 2' originate from Moos Heunicke & Vejlgaard (2021), and their explanations can be found there
- Column E: Built with CE principles in mind means the building itself, its design or construction is advertised as being circular by its stakeholders
- Column F: Yes/No-criterion based on the data gathered in columns G-J
- Column G: 'CE Categories of Principles applied' refers to the explanations given in Nußholz et al. (p.2, 2023)
- Column H: 'Circular building strategies applied' refers to the strategies presented for new built projects in Nußholz et al. (p.2, 2023)
- Column I: The 'Circular in/out/both?' assesses whether the examined project takes into account the materials and products going IN the project, the materials and products going OUT the project after its lifetime, or whether BOTH are taken into account.
- Column J: 'Has building been dismantled / recycled / demolished?' examined whether the assessed project is still operational and in place. Satellite-view and/or Streetview (when available) in Google Maps was used to ascertain whether the reference project is still in place (care was taken to check the date of the satellite images)

#	Project Name	Data	Description	Built with CE principles (Y/N)	Adheres to CE Principles or has followed circular building strategies (Y/N)	CE Categories of Principles applied	Circular building strategies applied	Circular In/Out/Both?	Has building been dismantled / recycled / demolished?	Source
1	Circular Retrofit Lab	Year: 2019 Type: Research Location: Brussels, BE Architect: n.a. Developer: VUB Size: 180 m2 StructureMA: Concrete StructureSY: Column/Beam Flexibility: Technical Principle 1: Reconfiguring Principle 2: Separation	The Circular Retrofit Lab is a pilot project tested and implemented different scenarios for the reuse and refurbishment of the VUB Campus' prefabricated student housing, without generating a large amount of waste. Strategies have been explored for internal transformations, external transformations, and the module's multiple functional reconfigurations. Depending on their expected rate of change in the floor plan, three different types of walls were defined, analyzed, constructed, and transformed: walls with (1) a high rate of change, (2) a high degree of flexibility for the integration of technical infrastructure and 3) a low rate of change. The circular refurbishment tested dismountable, adaptable, and reusable solutions for maximizing waste reduction. The pilot developed a co-creative process all along the (re)design, (re)build, (re)use, repurpose or dismantling phases. This necessitated a close collaboration with all the value network stakeholders and future users in the early development phase. The research also investigates if new circular business models can be developed based on reversible design principles. "Circular Retrofit Lab." Retrieved 09.08.2023, from: https://www.bamb2020.eu/topics/pilot-cases-inbamb/ retrofit-lab/	*Yes*	*Yes*	*Narrowing, Slowing, Closing*	*Design optimization* *Design for durability and long-life* *Design for easy maintenance and repair* *Design for reversibility* *Design for reuse* *Secondary materials and components* *Avoidance of (carbon-intensive) components and structural elements* *Maintenance and repair with minimum resources*	*Both*	*No*	Moos Heunicke & Vejlgaard, 2021

#	Project Name	Data	Description	Built with CE principles (Y/N)	Adheres to CE Principles or has followed circular building strategies (Y/N)	CE Categories of Principles applied	Circular building strategies applied	Circular In/Out/Both?	Has building been dismantled / recycled / demolished?	Source
2	B.R.I.C	Year: 2017-2020 Type: Research Location: Brussels, BE Architect: n.a. Developer: EFP Size: 70-130 m2 StructureMA: Timber StructureSY: Column/Beam Flexibility: Technical Principle 1: Reconfiguring Principle 2: Accessibility	Entirely built by young trainees, the BRIC building is a sustainable, scalable and reversible construction developed by the interdisciplinary Brussels training centre, EFP during three consecutive academic years, starting in autumn 2017. The BRIC is being assembled and disassembled on yearly basis. Each transformation is accompanied by a change in function: from an office (2018) to a shop (2019) and eventually an acoustic laboratory (2020) for training EFP students. During its transformations, the project is testing the capacity of the construction to evolve in size and functionality. The ability of the project to be transformed and adapted to new functional needs makes BRIC a valuable scalable project. Making use of its reversible characteristics, such as the removable foundation, the building can be implemented in different places with minimal ecological footprint and ease of assembly to accommodate different functions. "Build Reversible In Conception (B.R.I.C.)." Retrieved 09.08.2023, from: https://www.bamb2020.eu/topics/pilot-cases-inbamb/retrofit-lab/	*Yes*	*Yes*	*Narrowing, Slowing, Closing, Regenerating*	*Design optimization* *Dematerialization and lightweight construction* *Design for durability and long-life* *Design for easy maintenance and repair* *Design for reversibility* *Design for reuse* *Materials with low embodied carbon* *Secondary materials and components* *Avoidance of (carbon-intensive) components and structural elements* *Waste prevention in construction* *Low-carbon construction equipment* *Maintenance and repair with minimum resources*	*Both*	*Yes*	Moos Heunicke & Vejlgaard, 2021

#	Project Name	Data	Description	Built with CE principles (Y/N)	Adheres to CE Principles or has followed circular building strategies (Y/N)	CE Categories of Principles applied	Circular building strategies applied	Circular In/Out/Both?	Has building been dismantled / recycled / demolished?	Source
3	GTB Lab	Year: 2018 Type: Research Location: Barendrecht, NL Architect: n.a. Developer: GTB Lab Size: 24 m2 StructureMA: Steel StructureSY: Column/Beam Flexibility: Technical Principle 1: Accessibility Principle 2: Reconfiguring	Realised in the framework of the GTB innovation centre for circular building in Heerlen, the Green Transformable Building Lab (GTB Lab) module has been developed around a reversible multifunctional steel frame which was filled by independent, exchangeable, standardised and reversible floor, facade and roof components. GTB Lab investigates the development of entirely new circular products by completely switching from the traditional construction approach. By considering simple principles such as standardization, universal connections and the lifespan of materials, the project investigates circularity. The joint participation of the construction industry in the development of the GTB LAB enabled the investigation of new business and operational models that makes a circular project feasible. "Green Transformable Building Lab (GTBL)." Retrieved 09.08.2023, from: https://www.bamb2020.eu/topics/pilot-cases-inbamb/retrofit-lab/	*Yes*	*Yes*	*Slowing, Closing*	*Design optimization* *Design for durability and long-life* *Design for easy maintenance and repair* *Design for reversibility* *Design for reuse* *Waste prevention in construction*	*Out*	*Unknown*	Moos Heunicke & Vejlgaard, 2021
4	The Circular Building	Year: 2016 Type: Prototype Location: London, UK Architect: n.a. Developer: Arup Size: n.a. StructureMA: *Steel* StructureSY: Column/Beam Flexibility: Technical Principle 1: Accessibility Principle 2: Replaceability	Designed and delivered as a prototype for the 2016 London Design Festival, the Circular Building is one of the first in the UK built to satisfy Circular Economy principles. Along with their partners, Arup refined the application of existing prefab construction techniques, integrating open-source details with materials that are inherently circular. The architectural design team worked with Arup's engineers to produce and test details that applied fine-tuned engineering rather than mechanical fixings; the result is an extremely low-waste, self-supporting and demountable SIPS wall system. Clamp connections between the wall and recycled steel frame ensure that both can be repurposed in the future. The cladding and decking are sustainably sourced heat-treated timber that is durable and recyclable. Every component of the building was interrogated to reveal its potential circularity. This enabled the team to produce a Materials Data Base, collating, for the first time, information on the production, material substance and next use of each asset. Archello. "The Circular Economy Building | Arup Associates." Retrieved 09.08.2023, from: https://archello.com/project/the-circular-economy-building.	*Yes*	*Yes*	*Slowing, Closing*	*Design optimization* *Design for easy maintenance and repair* *Design for reversibility* *Design for reuse* *Materials with low embodied carbon* *Secondary materials and components* *Waste prevention in construction* *Maintenance and repair with minimum resources*	*Both*	*Unknown*	Moos Heunicke & Vejlgaard, 2021