# D3.5

# Catalogue and guidelines for circular building elements (Part I)

## Practical catalogue for building professionals (Part I)

*Lead beneficiary:* EPEA GmbH – Part of Drees & Sommer

July 2023

Version 02

Type of deliverable: Report

| ***Dissemination level*** | | |
|---|---|---|
| PU | Public | X |
| PP | Restricted to other programme participants | |
| RE | Restricted to a group specified by the consortium | |
| CO | Confidential, only for members of the consortium | |

The project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 869336.

| *History of changes* | | | |
|---|---|---|---|
| *Version* | *Date* | *Organisation* | *Modifications* |
| 01 | 17.01.2023 | EPEA | - |
| 02 | 19.07.2023 | EPEA | Chapter 4.5 |
| | | | |



| *Main author(s) (in alphabetical order)* | | |
|---|---|---|
| *Name* | *Surname* | *Organisation* |
| Karoline | Habt | EPEA |
| Pascal | Keppler | EPEA |
| Johanna | Staab | EPEA |
| | | |



*ICEBERG website:* [www.iceberg-project.eu](http://www.iceberg-project.eu)

## Executive Summary

40% of total greenhouse gas emissions in Europe are caused by the construction sector and half of all raw materials are used by this sector. These alarming figures make it imperative to rethink the way we use resources and to adapt our economic system. This path is also supported by the EU, individual countries as well as local authorities by passing an increasing number of legal guidelines on the topic of sustainability and circularity in the construction industry. The transformation from a linear economy to a circular economy requires to fulfill some measures and to adhere to different principles. These principles are about effectiveness, efficiency, optimization and, above all, closed loops that allow systems to be reused and regenerated. The well-known school of thought Cradle to Cradle extends the approach of circular economy even further and aims not only to reduce negative impacts, but additionally to make a positive contribution. The criteria that must be met for materials and building products to be aligned with our definition of a circular construction economy are Material Health, Carbon Footprint, Material Origin, Material Recovery, Flexibility and Separability. All six categories are interconnected and by gaining knowledge about one category, conclusions can be drawn for another. If all of these are influential in construction projects, a high value for circularity can be achieved.

This report thus deals with the guidelines for circular construction in addition to the Cradle to Cradle approach in the construction sector. In particular, it shows how this circularity can be achieved and what methods exist for its implementation. For this purpose, the results of various interviews with building professionals as well as a market research are presented first, so that insights into the current approach to circular construction can be obtained. Thereby, it becomes clear, among other things, that there are no standardized processes for the implementation of circular building among planners and that many situations an uncoordinated approach is pursued. From these and other findings on the status quo, the needs and concrete requirements of building professionals for circular construction are then derived. As the market research shows, there is a wealth of information, material libraries, and frameworks available online. There are also some tools that cover sub-sets of circularity and other important environmental sustainability subjects regarding the building industry. The takeaway from this, however, is that there is a need for a consistent process and central solution for assessing circularity, for which there is no additional effort compared to normal planning processes. One implementation option for this is in the form of a software solution based on a combination of material libraries with data on the circularity status of individual components and a plugin for BIM planning software.

## Acronyms

BCI: Building Circularity Index

BIM: Building Information Modelling

BREEAM: Building Research Establishment Environmental Assessment Methodology

C2C: Cradle to Cradle

CE: Circular Economy

DACH: Germany, Austria, Switzerland (Deutschland, Österreich, Schweiz)

DGNB: German Sustainable Building Council (Deutsche Gesellschaft für nachhaltiges Bauen)

EPD: Environmental Product Declaration

ESG: Environmental Social Governance

LCA: Life Cycle Assessment

LEED: Leadership in Energy and Environmental Design

MCI: Material Circularity Index

## Contents

## List of figures



## List of tables

# 1. Introduction

Creating a built environment that is circular requires building products that are designed the way they can reenter the cycle. Furthermore it requires planners to understand and apply circularity on their everyday work. ICEBERG therefore discovers solutions for manufacturers on how to redesign their products as well as for planners on how to integrate these changing requirements in their planning process.

The following report focuses on the journey of architects as key players in implementing circularity in buildings. Their very early decisions on the design of a building paves the way for a more or a less circular built environment. Currently architects are left alone with these additional requirements of circularity. It happens mostly on a voluntary basis and requires a lot of additional effort. In order to accelerate the transition towards a circular built environment architects need to be supported/empowered in integrating this additional task. Thus this report discovers the needs architects have when integrating circularity in their regular processes. In exchange with the architects/ users themselves solutions are developed on which guidance at which points of the planning process they need. This Report thus is intended to establish a basis on how to best set up and structure a catalouge for circular building elements that can be easily integrated into the usual workflows of architects. The actual content of the catalogue will be developed hereafter and included in D4.4

## 1.1. Objectives and research questions

The requirements of this report on the occasion of the ICEBERG project were therefore to develop guidelines for circular construction. For this purpose, the target was to inform the stakeholders about different possibilities of concrete realization, especially with regard to recycling and reuse processes. These options for action should then result in the description of a user-friendly and decision-support context that enables the transition to a circular environment.

The target questions that emerged from this set of requirements were, first, what circularity means in the construction industry and why it is so important. In addition, there was the question of what circular construction comprises and what possibilities do exist here. In a final step, methods for implementation had to be developed.

## 1.2. Structure of the report

In order to answer these guiding questions, this report first looks at the relevance of the topic. To this end, the current challenges facing the construction industry in terms of environmental impact will be highlighted. The emerging policy frameworks are also addressed. Afterwards, a general definition is provided of what circular economy means and how it can be distinguished from a linear economic system. Besides introducing different schools of thought or circular economy, the famous approach "Cradle to Cradle" that requires the implementation of a few principles is presented here. At the end of this introduction, a link is made between the circular economy in general and the construction industry.

The third chapter examines different methods for measuring circular economy in the construction sector. For one approach the definitions for each of the contained categories material health, carbon footprint, material origin, material recovery, flexibility and separability is given. It also explains how these can be determined and assessed quantitatively.

The last chapter is the main part of the report: Here, the methodological approach that was implemented is outlined first. In order to be able to derive the concrete implementation instructions, the as-is status is first analyzed here. In doing so, it is determined how planners currently deal with the topic of circular construction and where certain barriers are encountered. In addition, an overview of current tools for assessing circularity in construction is presented, and sources of information and specific framework programs are dealt with. From this, the needs and requirements of architects can be derived with regard to the implementation of circular construction. Before the conclusion finally summarizes the learnings, a software solution is proposed that tries to implement these findings.

# 2. From linear to circular economy

## 2.1. Current challenges in the construction sector

The construction industry is one of the largest sectors of the European economy. In recent years, there has been vast progress in improving the energy efficiency of buildings, but there has been little progress on the issue of use as opposed to reuse and recycling. Supply and demand are not well matched in the construction sector. Buildings consume about the half of the energy needs in Europe and are responsible for about 40% of total greenhouse gas emissions. Furthermore, the construction sector in Europe uses about 50% of the total raw materials [EU Commission, 2019, p.5]. In addition to these environmental impacts, construction and demolition projects are also responsible for about one third of all waste generated in the EU. These exemplary figures indicate that a resource transformation in the construction sector is well overdue. However, the construction industry is at a turning point: a variety of new building technologies and business models are emerging, which, together with changing consumer behavior, are driving the transition to a circular economy.

As a result from this, new requirements are emerging at the political and legal level as well. This is happening both at the EU and country level, but also on a smaller scale at the municipal level. One of the most important new framework conditions on the European side is an adjustment of the ESG regulations. This has resulted in the EU Taxonomy as part of the European Green Deal. The EU Taxonomy provides a common definition of what may be considered as sustainable. It is a classification system that lists environmentally sustainable economic activities and is used to support the implementation of the European Green Deal in order to act as an incentive for the expansion of sustainable investments. It provides policymakers, companies and investors with appropriate definitions of which activities can be classified as environmentally sustainable. This can protect against green washing and increase the climate friendliness of companies.

The Taxonomy Regulation was published in the Official Journal of the European Union on June 22, 2020 and entered into force on July 12, 2020. It lays the foundation for the EU Taxonomy by establishing four overarching criteria that an economic activity must meet to be considered environmentally sustainable. The framework sets thresholds for economic activities that make a substantial contribution to six environmental goals. These environmental goals are mitigation of climate change, adaptation to climate change, sustainability and protection of water and marine resources, pollution prevention and control, and transition to a circular economy.

The construction industry is a key factor in meeting these and worldwide climate protection targets. Economic growth, demographic change and increasing comfort requirements pose major challenges for sustainable development in the construction industry, which is why it is important to take a holistic approach here. This report addresses an approach for a transition to a circular economy in the construction industry. To this end, in this chapter the term circular economy will first be defined, followed by an explanation of the cradle to cradle approach as one school of thought in the circular economy, before finally the main aspects of circular economy in the construction sector will be outlined.

## 2.2. Definition circular economy

The just mentioned current challenges that lead to the necessity of new regulations have a common origin: Our system is based on a linear economy. The use of finite resources in combination with ever higher consumption due to increasing demand and population growth, lead to raw materials becoming increasingly scarce. This leads to an increasing distribution imbalance, rising raw material costs and thus also to social injustice. Environmental problems arise, among other things, from the disposal and incineration of waste materials in landfills. The linear economy is structured according to the "take - make - dispose" principle, which, in combination with a lack of a holistic approach to urban management, leads to economic losses caused by construction waste and to negative environmental impacts. The latter include poor air and water quality, noise pollution, and the release of toxins and greenhouse gas emissions. Since this system is not designed for sustainable growth and scaling, it cannot work in the long term.

Instead of following a linear take-make-dispose approach, economy should restore itself into what is, in theory, an infinite cycle of make and use. In this way, it is possible not to dispose resources after a short period of use, as it has been the case up to now, but to preserve their quality and thus enable them to be recycled. A response to the linear economy is thus the circular economy, which seeks to decouple growth from the consumption of finite resources. It is an approach to a renewable and regenerative economy that benefits the environment as well as businesses and society. The Circular Economy can be defined as an economy that provides multiple value-creation mechanisms which are decoupled from the consumption of finite resources.

The main principles on which this definition is based on, support its implementation: First, a system should be structured as effectively as possible so that waste and pollution are avoided. Therefore, the economic externalities that have a negative impact on human health and nature should be identified and eliminated. This includes, for example, air, soil and water pollution, the release of toxins or greenhouse gas emissions. The second principle is based on the approach of optimizing resource yields. Products, components and materials should be used as long as possible to maintain their value. Consequently, a closed-loop system must be created allowing the products to be reused, reprocessed and recycled so that their service life is extended. Depending on the type of product and application, both the biological and technical cycles must be implemented. The third principle aims at regenerating natural systems. In this process, natural capital should not only be preserved but continuously improved. This is made possible by promoting conditions favorable to regeneration, such as the use of renewable energy sources. If these principles are applied to create a new renewable and regenerative economy, the ecosystem can be preserved and the yield increased over time. This in turn leads to growth and prosperity by extracting value from existing infrastructure and products.

Thus, a circular economy includes several features that determine different phases during the product's life. For example, the selection of materials for a particular product takes into account how it can be recycled so that the components can be efficiently recovered as secondary raw materials. In addition, the compatibility of materials with the environment should be assessed at the concept stage so that health and environmental procedures can be eliminated during recycling. Instead of being disposed of directly, products should first be repaired if they are damaged or reused and refurbished in such a way that they circulate as long as possible through reuse or second use.

## 2.3. Schools of thought on circular economy

Although what has just been described combines the core ideas of various schools of thought on circular economy, there is no one single definition. This is because the perspective on circular economy has evolved and diversified since the 1970s, when the concept first emerged. Five of the most prominent schools of thought that have arisen are Industrial Ecology, Cradle to Cradle, Performance Economy, Blue Economy and Biomimicry. Various descriptions of these can be found in the academic and grey literature, from which a variety of principles can be derived.

The goal of Industrial Ecology is to consider the industrial system and the biosphere as a whole, so that a conceptual framework can be provided in the economic transformation process. This results in measures for environmental protection and optimized resource use that are in harmony with economic aspirations. The Performance Economy aims to implement a shift in thinking from "doing things right" to "doing the right things" by decoupling economic growth and resource consumption. The Blue Economy is based on innovative business models that both have a positive impact on the environment and contribute to economic growth. The core idea of Biomimicry is to look at how nature solves problems and to link the lessons learned with human technology so that solutions are sustainable over the long term. Thus, circular economy can be seen as the scope of this school of thought, as analogous to natural systems, there should be no waste and all organisms should circulate.

The Cradle to Cradle school of thought is explained in more detail below, as the measurement principles of circular economy selected for this report are based on this approach. Cradle to Cradle (C2C) is applicable to the building sector as well as to any other industry. The aim is not only to minimize negative impacts, but rather to make a positive contribution. In this way, effectiveness and efficiency are combined on the way to a holistic circular economy.

The C2C approach is based on several fundamental principles: One of them is the thesis that every nutrient remains a nutrient. This means that there are no waste products and all materials can be reused an infinite number of times. For this principle to work, two different material cycles are assumed. The following figure shows the biological cycle on the left, which includes products that are directly related to the natural environment. Here, products go through a process from production to use and subsequent decay, which in turn serves as a nutrient for new products. In order to preserve the biosphere, it is imperative that all materials in this cycle are safe for human health and compostable. In the technical cycle, on the other hand, the products are reprocessed as technical nutrients after their life cycle in a specific application so that they can be used again in another application.

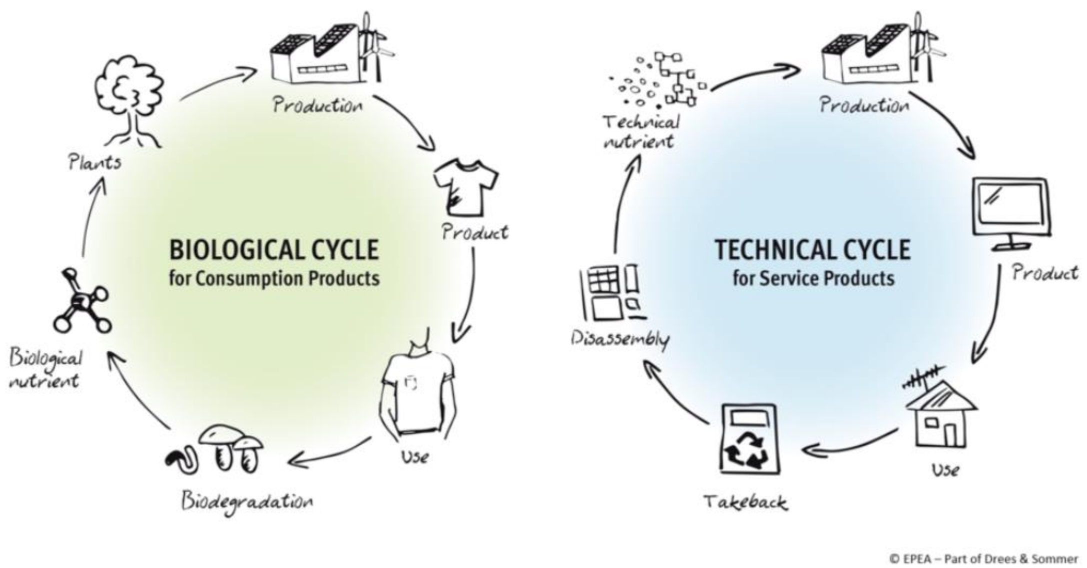



Figure 1 Biological and technical cycle of Cradle to Cradle - Source: EPEA

Another fundamental principle that is firmly integrated in the Cradle to Cradle approach is the exclusive use of renewable energy sources. In addition, diversity is to be taken into account and supported, as is also common in nature.

## 2.4. Circular economy in the construction sector

These aspects of closed-loop thinking are equally applicable to the construction sector. However, sustainability considerations in the construction sector often only include measures to reduce $CO_2$ and environmental impacts, other parts are often neglected or not taken into account.

The large amounts of materials produced and waste generated in the construction sector are coupled with some challenges. This is justified by the fact that most of the building materials used today require large amounts of resources for their production and are rarely recycled, neither biologically nor technically. To date, the life cycle of a typical building material often follows the linear cradle-to-grave model. After the material is extracted, it is processed into a building component. Once the life of the component is reached, it is either downcycled or ends up as construction waste. Consequently, the value of the material that was created during the extraction of the raw material is lost here. In the circular economy, on the other hand, we question the current process and propose a new model that retains the values. When material loops close, it leads to less construction waste, less $CO_2$ emissions and therefore minimizes the consumption of resources.

In the construction industry, circular economy would also mean that the urban environment is based on a circular system. This would involve integrating green infrastructure such as parks into long-life or mixed-use buildings. In this context, the buildings could be designed according to a modular principle that incorporates recyclable and non-toxic materials. Buildings are thereby able to produce energy and nutrients rather than just consume them, enabled by fully closed loops for water, food, materials, and energy. On a small scale, this solution turnover has already been exemplarily implemented in some buildings, but so far it gets little attention from companies.

# 3. Circular building economy

## 3.1 Methods for measuring circularity in the construction sector

In order to apply these previously announced principles of circular economy to the building sector, it is necessary to select an appropriate measurement method. For example, the Material Circularity Indicator of the Ellen MacArthur Foundation, the Urban Mining Index, the Building Circularity Index, the resource passport by the German Sustainable Building Council (DGNB Gebäuderessourcenpass) as well as some methodological aspects of the ISO 20887 are common methods for assessing circularity and will be explained in brief. Beside these, performing a life cycle assessment or adhere to the Level(s) Framework is meaningful in this context as well.

<u>Material Circularity Indicator</u>

With the Material Circularity Indicator or MCI the material flow and thus the extent of circularity is mapped on a scale from 0 to 1. The MCI is used primarily by product designers and purchasers as a basis for decision-making, but is also used for reporting or for evaluating companies. In their methodology, the higher the score on the scale is, the more circular is the product considered. Thus, an MCI of 1 means that all raw materials consist of reused or recycled materials and that waste is reused without loss at the end of a use phase. An MCI higher than 0.1 is a product that consists entirely of linear material flows, but has a higher utility than an average industrial product. A value of 0.1 represents an average product where all materials are in primary use and will not be reused. If the value is less than 0.1, the product has a lower utility than an average industrial product and consequently a shorter service life and a lower intensity of use.

Urban Mining Index

The Urban Mining Index systematically records and ranks buildings and components in order to classify them along the entire life cycle. Both the incoming materials are assessed and the resulting values and waste materials are calculated and evaluated according to the quality levels of their post-use. Reuse and high-quality recycling are ranked higher than downcycling. In addition, the economic efficiency of selective deconstruction is predicted based on the amount of work and a probability value for reuse. The Urban Mining Index can then be calculated as a percentage from the weighted circular potential from pre-use and post-use.

Building Circularity Index

The Building Circularity Index, or BCI for short, is a scientific measurement tool for determining the circularity potential of a new or existing building. It combines various recognized measurement methods for environmental impact and circularity into one integrated instrument. While other measurement tools focus mainly on the use of raw materials and resources in a building as a whole, the BCI also provides insight into the individual parts of a building. This involves determining a value between 0 and 1 for the material-related environmental impact of a building per square meter of gross floor area. The lower this value, the lower the environmental impact and circularity.

Resource passport by the German Sustainable Building Council

In the resource passport, the essential information on resource consumption, climate impact and recyclability is to be transparently stated individually for each building. To this end, data is compiled and evaluated in the categories ingredients and use of circularly valuable materials, environmental impact / greenhouse gas emissions / energy use, circular use, as well as conversion / deconstruction friendliness and subsequent use. In this way, it is intended to provide the information necessary to make the best use of resources in various scenarios such as urban mining, redevelopment and demolition. At the time as this report is being published, this methodology is still in a draft-phase but will be referenced here nonetheless, since it is expected to experience high adoption rate in Germany.

ISO 20887

The ISO 20887 provides an overview of design for disassembly and adaptability principles and potential strategies for integrating these principles into the design process. This is thus less of a methodological evaluation system and more of a framework. The adaptability principles are versatility, convertibility and expandability. Whereas the principles for disassembly include the aspects independence with focus on reversibly connections, the avoidance of unnecessary treatments and finishes, simplicity, standardization and safety of disassembly. Furthermore the importance of support processes for reuse business models is outlined in regard to reusability, restorability, re-manufacturability as well as increased recycling and future recycling.

Circularity Passport for Buildings

Within the research project Buildings as Material Banks (BAMB, 2015-2019) a set of indicators for circular buildings was developed. Within the past five years this approach was adapted and applied to over 100 real cases by EPEA. The application to real projects demanded simultaneous improvement. The indicators used include the following: Material Health, Embodied Carbon, Material Origin, Material Recovery, Flexibility, Separability. Each of these categories is allocated to characteristics that in turn can be assessed within certain quality ratings. The described measurement methods reveal that the construction sector is about to find a common language and a common measurement method when it comes to the circularity of a building. It needs to be stated that understanding the method in detail is not always possible with the information provided publicly. Also it is not always clear to which extent these approaches were used and adapted to real world projects.

Having used and improved the approach and methodology of the circularity passport the past five years, it provides a good basis to make this method further accessible. Also it is important to note, that the methodologies specified above are very similar in most aspects. All of them distinguish between what EPEA calls “Material Origin” and “Material Recovery”. Also most of them include a metric for measuring a disassembly potential. The analysis of embodied carbon mostly comes separate within an LCA and “Material Health” is mostly omitted.

For this reason the report explains in the following the methodology in detail before exploring how it can be integrated as a tool for building professionals in the planning process.

## 3.2. Material Health

The term "Material Health" describes the assessment of the materials contained or used and their composition in the context of a holistic sustainability analysis. Not only criteria that are toxic or hazardous to human health play a role, but also those that are harmful to the environment. The ingredients are evaluated along their complete life cycle, from production to recycling. Consequently, a material is only considered healthy if it is designed in such a way that it does not have a negative impact on humans or the environment during any phase of its life. Buildings should be developed in such a way that they are beneficial to people and nature.

If all materials are carefully selected and tested with regard to their pollution and exhaust fumes, the following three goals can be achieved: By installing only healthy and positively rated materials, the health of building users can be protected. In addition, pollution from fine particles in the air, water and soil can be prevented. The evaluation of materials and the associated detailed knowledge of all components also paves the way for recycling processes, as these are only possible with a high level of material knowledge.

In the perspective of EPEA it is important to measure “Material Health” as part of a whole-building circularity metric as the presence of harmful substances is likely to make high-value recycling impossible in future.

The following table shows what a specific product categorization might look like. In accordance with the displayed quality factor, the entire building can then be categorized.

| Rating Name | Quality Factor | Rating Description |
|---|---|---|
| **optimized** | 1 | Proven to have improved ingredients over industry standard and no ingredients that are on the C2C Banned List or classified as CMR. |
| **improved** | 0,75 | Demonstrably improved ingredients compared to industry standard |
| **standard** | 0 | Ingredients that meet industry standards. |
| **problematic** | 0 | Problematic ingredients that do not meet industry standards. |
| **Unknown / Not assessable** | 0 | There is not enough information available for an evaluation. |

Table 1: Rating Categories for Material Health in a Building

The weighting in this category is taken by piece. So, assuming that an amount of n different materials or products was used in the building, to get a score on the building level, the calculation would be the following:

$$Score(\text{Material Health})[\%] = \frac{\sum 1 \times HEAQualityFactor}{n_{Distinct\ Materials}}$$

## 3.3. Embodied Carbon

In order to determine a value for the carbon footprint, it is necessary to perform a life cycle assessment (LCA) for the building, including its products and materials. The carbon dioxide content is considered as Global Warming Potential, which is why this category receives a lot of attention from the public and is therefore classified as one of the most important.

Since the scope of each LCA usually varies depending on the topic, it is important to agree on a common scope when comparing projects. In particular, green building certification systems (such as LEED, BREEAM, or DGNB) provide commonly used and well-tested scopes. Among these, also the scope of the German Sustainable Building Council (DGNB) is considered as the one that provides one of clearest description of an LCA scope. Therefore, the DGNB scope is used as the basis for calculation in this report.

The DGNB specifies the modules to be included as A1-A3, B4, C3, C4 and D. Data sets for these modules are generally available for each material type. Product-specific data take precedence over generic data sets (industry average). Defining the scope of the calculation to these modules allows to conduct a comparison of the results for different projects.

| LC PHASES | A 1–3 | | | A 4–5 | | B 1–7 | | | | | | | C 1–4 | | | | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | PRODUCTION | | | ERECTION | | USE | | | | | | | END OF LIFE | | | | |
| | RAW MATERIAL SUPPLY | TRANSPORT | MANUFACTURING | TRANSPORT | CONSTRUCTION / INSTALLATION | USE | MAINTENANCE | REPAIR | REPLACEMENT | REFURBISHMENT | OPERATIONAL ENERGY USE | OPERATIONAL WATER USE | DECONSTRUCTION DEMOLITION | TRANSPORT | WASTE PROCESSING | DISPOSAL | POTENTIAL FOR REUSE, RECOVERY AND RECYCLING |
| Modules | A1 | A2 | A3 | A4 | A5 | B1 | B2 | B3 | B4 | B5 | B6 | B7 | C1 | C2 | C3 | C4 | D |
| Minimum to include | x | x | x | | | | (x) | | x | | (x) | (x) | | | x | x | x |

Table 2: DIN EN 15978 modules for lifecycle assessment on building level according to DGNB International version 2020

## 3.4. Material Origin

In order to be able to evaluate the material origin of a material as positive, two criteria have to be implemented. On the one hand, the product should consist of secondary or renewable materials, and on the other hand, they should have a high environmental as well as social quality.

The former is easier to identify in many cases, as secondary and renewable materials are often identified as such. For a better assessment, a categorization into the following subgroups is advisable: Pre-consumer recycled content, Post-consumer recycled content, Renewable content and Primary (virgin material) content. Therefore, to drive circularity in the building sector, the use of non-renewable primary materials should be strongly minimized and replaced by recycled resources.

Much more difficult to identify, compared to the quantity of secondary and renewable materials, is the quality of these. Particularly in the case of post-consumer secondary materials, which often come from unknown or varying origins, a reduced technical quality is to be expected. This is accompanied by the risk of contamination by toxic chemicals. The problem with renewable and primary materials, on the other hand, is the risk that they have been extracted and processed under environmentally hazardous or socially problematic conditions. To counteract this, it is essential to evaluate the origin of each material. One possibility for such an assessment is for example to request supply chain certificates, as these confirm the material quality from an independent party and thus create transparency.

The following table gives an overview of how the material origin could be classified and evaluated. Based on the quality factor, it can be seen that each material should be either a secondary material or a sustainably renewable material.

| Rating Name (SRC) | Quality Factor | Rating Description EN |
|---|---|---|
| **Secondary material** | 1 | Products made from secondary material. |
| **Sustainably Renewable Material** | 1 | Products that are made of renewable material from certified sustainable sources. |
| **Primary material** | 0 | The new raw material has never undergone any processing other than manufacturing. |

Table 3: Rating Categories for Material Sourcing in a Building

Under current conditions, it is hardly possible to achieve a quality factor of 1 for all materials used, as the market does not permit this. Although a large part of the building products on the market are made exclusively from primary resources, there is a positive trend in the metal industry towards recycled materials and in the wood industry towards renewable products.

The weighting in this category is taken by the mass of each material. So, to get a score on the building level, the calculation would be the following:

$$Score(\text{Material Sourcing})[\%] = \frac{\sum MaterialMass\ [kg] \times SRCQualityFactor}{\sum MaterialMass\ [kg]}$$

## 3.5. Material Recovery

One of the most important aspects of circular construction is the reusability of materials at the end of the building's life cycle. In order for the components of a building to be reusable, they must be designed and constructed in a certain way. The idea is that they can be recovered in their original form and then reused as raw materials for new products that do not contain harmful substances. Thus, a high-quality recycling process must be carefully worked out in the early stages of designing a product. Aspects that should be considered in this context include the possibility of performing simple maintenance and repair measures. In addition, efforts should be made to ensure that products can be disassembled into their individual components after disassembly. Material composites or surface coatings also play a crucial role here.

In this context, it is also important to be aware that there are different recycling scenarios. In current legislation, for instance, downcycling is considered as a form of recycling. For a holistic circular economy, according to our definition, only recycling of the same quality corresponds to the highest requirement level, as can be seen in the following table.

| Rating Name (REC) | Quality Factor | Rating Description EN |
|---|---|---|
| **Recycling** | 1 | The material can be recycled without significant loss of quality and thus replace a primary raw material of at least the same material quality. |
| **Downcycling** | 0,5 | The material experiences a significant loss of material quality through recycling. |
| **Energy recovery** | 0 | Material is used as substitute fuel (min. 11 MJ/kg calorific value). |
| **Landfill / Thermal disposal** | 0 | Material is disposed in landfills or incinerated without energetic benefit (calorific value < 11 MJ/kg). |
| **Unknown / Not assessable** | 0 | There is not enough information available for an evaluation. |

Table 4: Rating Categories for Material Recovery in a Building

The weighting in this category is taken by the mass of each material. So, to get a score on the building level, the calculation would be the following:

$$Score(\text{Material Recovery})[\%] = \frac{\sum MaterialMass\ [kg] \times RECQualityFactor}{\sum MaterialMass\ [kg]}$$

## 3.6. Flexibility

Flexibility implies that coherent construction systems can be dismantled non-destructively as far as this is economically feasible. This enables simple replacement processes of the functional units, which in turn leads to a high adaptability of the buildings. As a result, reconstruction is significantly facilitated, as is third-party application, which leads to a longer overall lifespan. This idea is derived from the principle of "How Buildings Learn" by Stewart Brand.

The following table and formula show a calculation method for building flexibility. The weighting in this category is taken by the mass of each building element.

| Rating Name (FLEX) | KPI Factor | Rating Description EN |
|---|---|---|
| **optimized** | 1 | The entire element can be removed and reused in its entirety. |
| **improved** | 0,75 | Functional units are all separable from each other. |
| **limited** | 0,25 | Functional units are partially separable from each other. |
| **problematic** | 0 | Functional units cannot be separated from each other. |
| **Unknown / Not assessable** | 0 | Not enough information is available for evaluation. |

Table 5: Rating Categories for Flexibility in a Building

$$Score(\text{Flexibility})[\%] = \frac{\sum ElementMass\ [kg] \times FLEXQualityFactor}{\sum ElementMass\ [kg]}$$

## 3.7. Separability

This category aims to enable structures to be disassembled back into their individual parts and components as far as possible, and on a large scale. To this end, detachable joining techniques are to be used instead of composite components. This applies, for example, to the facade (no composite thermal insulation system), the perimeter area (no bitumen coating or bonded PS insulation), wall surfaces (gypsum plaster), roof structures (bitumen roofing membranes and bonded insulation) and floor structures (bonding). As a result, separable construction systems are obtained.

| Rating Name (SEP) | KPI Factor | Rating Description EN |
|---|---|---|
| **Optimized** | 1 | Easily accessible material that can be separated by type. |

| | | |
|---|---|---|
| **Limited** | 0,5 | The material is separable but only with increased effort. |
| **Problematic** | 0 | The compounds are not separable or only with unprofitable effort. |
| **Unknown / Not assessable** | 0 | There is not enough information available for an evaluation. |

Table 6: Rating Categories for Separability in a Building

The weighting in this category is taken by the mass of each material. So, to get a score on the building level, the calculation would be the following:

$$Score(\text{Separability})[\%] = \frac{\sum MaterialMass\ [kg] \times SEPQualityFactor}{\sum MaterialMass\ [kg]}$$

Concluding the six categories presented, it becomes apparent that the circular building design is not only about reuse and recycling, but that further aspects have to be taken into account. In this context, the categories are mutually interdependent and beneficial for each other. Through the very detailed material analyses in the context of the evaluation of Material Health, important knowledge about the constituents and components is gained. This material knowledge can then be used to analyze the origin and recovery of the components and thus also to make conclusions about recycling and reuse. Flexibility and separability are also directly connected to these factors. Based on the data and the knowledge of which materials were used, where they come from and where they will go, the CO2 footprint can be determined more precisely.

# 4. Information and tools for circular building

Now that the political and environmental importance of implementing circularity in the construction industry has been presented, as well as various categories of circular construction, the following chapter presents the current situation and concrete needs for implementation. In a first step, workshops and an online survey were conducted to determine the status quo regarding circular design. Based on this, a market research was conducted with the aim to find out which tools and information sources are currently available to construction planners. Derived from these three approaches, it was then possible to determine the concrete needs of how planners envision the implementation of circular economy in the construction industry. At the end of this chapter, a software solution is presented, which is one possibility of how circular planning can be implemented in the everyday life of construction planners in the future, taking into account the insights gained from market research, workshops and the survey.

## 4.1. Methodical approach

Before presenting the results, the methodological approach will be outlined: For the purpose of finding out what needs building professionals have in regard to circular construction, several qualitative interviewing methods were applied: workshops, a survey as well as a personal interaction at a trade fair. Furthermore a market and literature research was conducted.

Method 1 – Workshops: In each of the 10 workshops, one to two employees from architecture firms interactively worked out how they deal with circularity and what concrete needs arise from it. The one-hour workshops, which took place between August and October 2022, were digital exchange formats in which an online whiteboard was jointly filled (see attachment 1). In addition to the question of what needs exist with regard to processes for circular building planning, the first step was to analyze the current status of the usual planning processes. Furthermore, an answer was sought to the question of which information would be needed at which time of the planning process. The interviewees from Germany and Europe had a focus or specific orientation on sustainability in general or circularity. The job titles of the interviewees included project manager, planner, BIM manager or sustainability consultant with core competencies in life cycle assessment, BIM, timber construction, circularity, life cycle analysis, resource efficiency, decarbonization and more. The schedule of the workshop included, after a short introduction of the attendees, a presentation of the framework project ICEBERG and an introduction to circular construction. Afterwards, general information about the architectural office, the competences of the participants and the usual project sizes and types were requested. After that, the exchange started about how the respondents currently implement circularity, and what their definition of it looks like. Here, they clustered which category they consider to be important and where they see the greatest difficulties in implementation. In addition, it was worked out what the demands of the building owners are with regard to circular building from the point of view of the architects. In a final discussion round, the focus was on the planning processes. Here, the needs for a process that is optimally aligned with the circular economy were derived from the current situation.

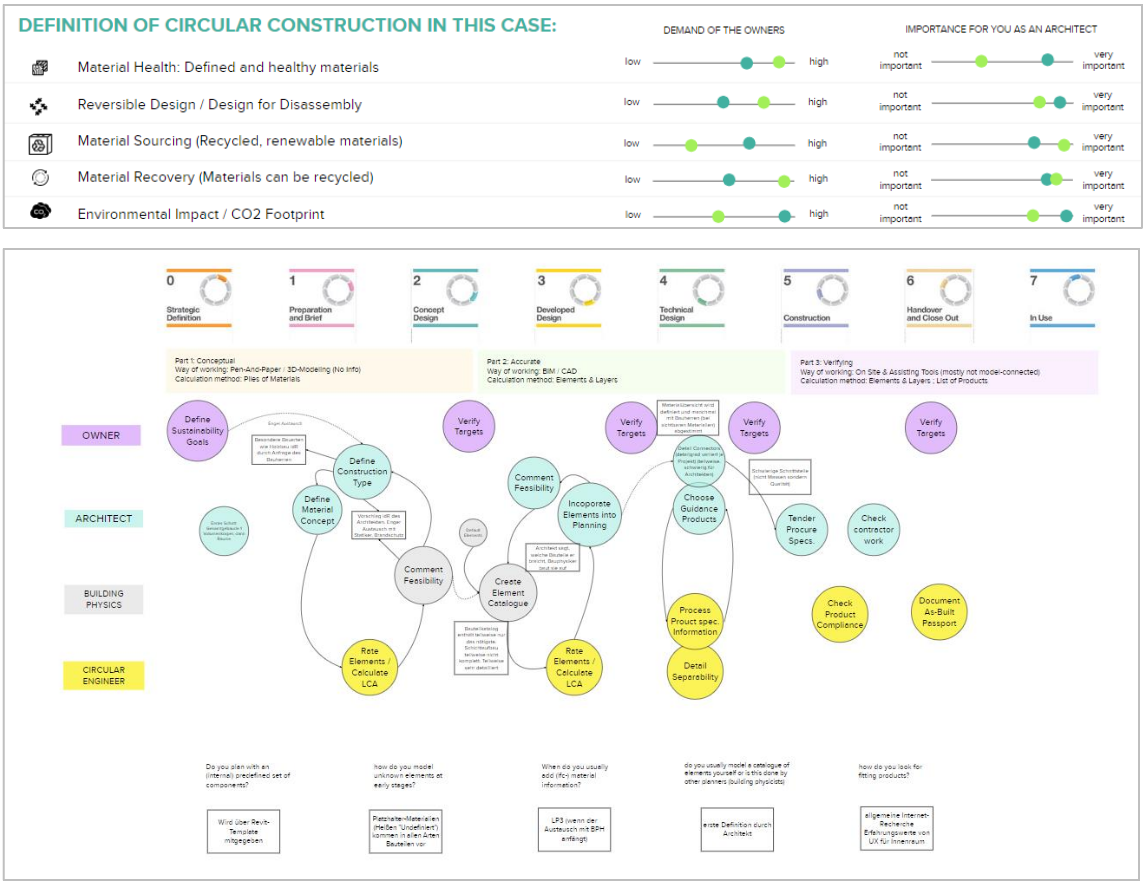



Figure 2 Screenshot of online whiteboard for workshop - Source: EPEA

Method 2 – Online surveys: In the online survey, around 50 architects answered 20 questions (see attachment 2), which also provided insights into their current processes as well as their needs for processes that allow for a circular economic system. From the six initial questions on the background of the companies and projects of the respondents, it emerged that both the office locations and the locations of the projects are distributed across Europe as well as, in some cases, worldwide. The second part of the questionnaire had the goal of inquiring about the current status of the implementation of circular construction in the surveyed architectural offices. The aim was to assess the role played by sustainability and circularity, which criteria are considered particularly important and which approach is being pursued for implementation. In the third part of the survey, the focus was on the planning process and the use of BIM, before the needs for dealing with a software tool for circular building planning were illuminated in the last part.

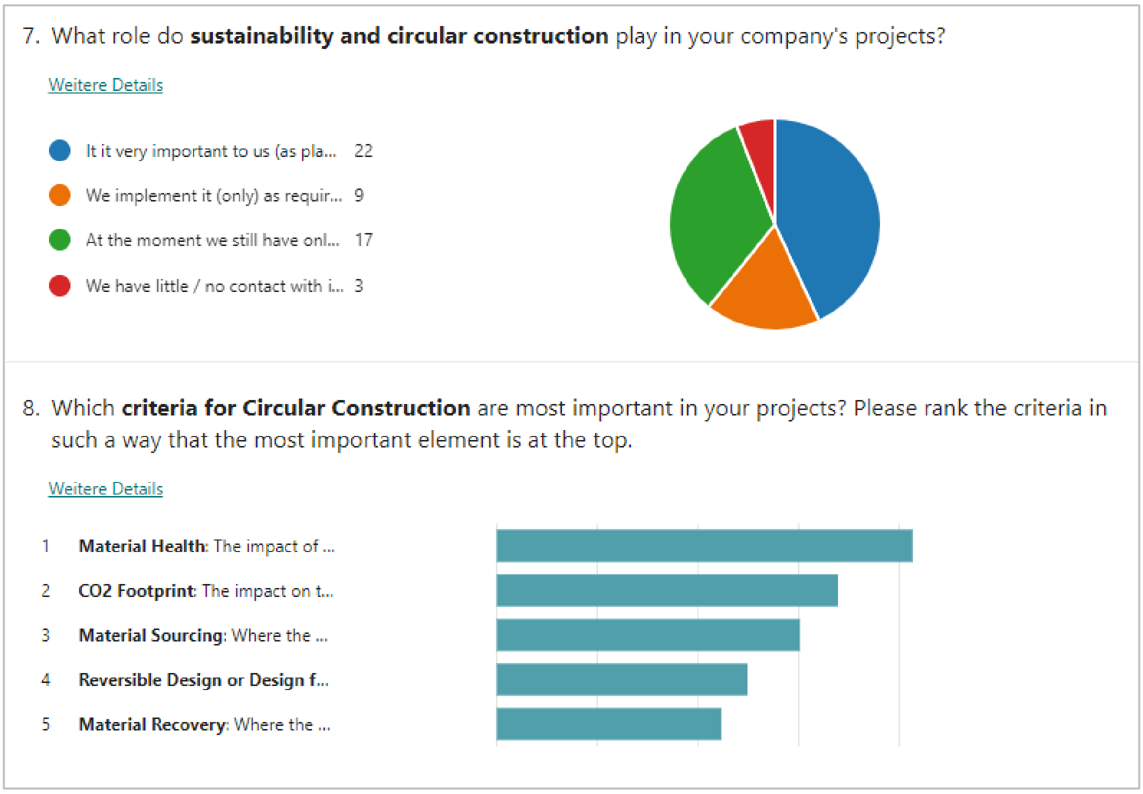



Figure 3 Screenshot of results of online survey - Source: EPEA

Method 3 – Market and literature research: Within the scope of a market research, it was investigated which tools are available for the calculation of circularity. A distinction was made between information sources and tools with which planners and other stakeholders in the construction industry can implement circular construction. For this purpose, solutions that are available in the European area were researched and examined. EPEA focused on the DACH region, while VITO took a closer look at the Benelux region and VTT concentrated on the Scandinavian region. The findings are listed in a detailed way within attachment 3.

Method 4 - Personal interaction at a trade fair: At a trade fair in Berlin (Designing the Future – Summit), a prototype for circular building design was presented to around 15 companies, with a request for feedback. The interview partners were one the one hand architects and planners, but also manufacturers of building products and consultants with a focus on sustainable building issues. The interview took place face-to-face and was summarized in key points afterwards. The main findings obtained here are largely consistent with the workshop and survey insights. However, some concrete needs could also be derived specifically for a tool as a solution of circular building design.

## 4.2. Status quo - Dealing with circular planning

This subchapter is dedicated to the current situation of how architects and planners deal with circular design. The data on this was collected in accordance with the explanation in the previous subchapter. For a better understanding of the status quo, the findings from workshops and surveys were clustered into the following categories: approaches and requirements for circular construction by architects, categories of circular construction, approaches and requirements for circular construction by clients and investors from the perspective of architects, and the influence of BIM (Building Information Modeling).

In the first category, architects' approaches and requirements for circular construction were summed up. The survey, addressed to architects and planners without a specific focus on sustainability, revealed that more than half of the respondents do not use a specific approach to implement circular construction in their projects, but rather take a different approach from project to project and from client to client. About a quarter of respondents align with sustainability certification systems such as DGNB, LEED or BREEAM. The third most common approaches are to use their own catalog of requirements or checklist and to form an internal competence team. Only 4 of the respondents indicated that they use a tool or software to implement circularity in their planning processes. The situation is a little different for feedback obtained from workshops with architects focusing on sustainable issues. Here, the approaches are also individual from office to office, but the approaches take place in a more coordinated manner so that a similar approach is taken for each project. The most important approaches here were the formation of an internal competence team or contact person for sustainability, the implementation of internal workshops and training courses, in order to create a uniform knowledge base. For the same goal, regular exchange takes place in some offices in the form of project reviews and expert talks. In addition, there are sometimes guidelines and checklists for concrete implementation. Consequently, the approach is not uniform and hardly defined, and in some cases uncoordinated. One possible explanation for this state of affairs is the fact that the implementation of sustainability and circularity in the construction industry is still a new topic, for which there are currently hardly any guiding processes.

To assess which categories of circularity play a critical role in building design, architects were asked in both the workshops and the survey to rate the components of circularity described in a previous chapter. To aid respondents' understanding, the "Flexibility" and "Separability" categories were combined into the "Reversible Design" category. During the workshops, architects were asked to rank each of the categories independently of the other categories in terms of importance. This revealed that the specific needs and environmental goals were weighted differently from architectural firm to architectural firm and, on a smaller scale, from project to project. On average, however, the categories carbon footprint and material origin were the categories that were rated as most important by most respondents. On the flip side, Material Health and Reversible Design were perceived as least important on average. In addition to evaluating the importance of the criteria of circularity, the implementation difficulties were also analyzed. Here, analogous to the importance rating, workshop participants were asked to independently rate each criterion as to how easy or difficult it is to implement. On average, implementation is rated easiest for Material Origin and most difficult for Reversible Design. A correlation between importance rating and ease of implementation can be seen in many places here. In the online survey, the task was slightly different: participants were asked to rank the criteria for circular construction and thus relate them to each other. As a result, Material Health and Carbon Footprint were ranked as most important overall, and Reversible Design and Material Recovery were ranked as least important. Nevertheless, the individual evaluation of the individual categories shows that the evaluation differs greatly from one another and, for example, 10% of the respondents also rated Material Health as the least important, and 6% of the respondents rated Material Recovery as the most important criteria. Furthermore, also here the weighting is evaluated individually, depending on the environment and knowledge level of the architect and the project. In addition to the proposed criteria for evaluating circularity, other possible categories were collected: Here, the need for master planning for circular-capable cities and the calculation of financial aspects to classify economic viability have become particularly clear. Other categories are the consideration of the life cycle of materials and products or the locality of material sourcing. Based on the fact that the given and further criteria were individually weighted, it can be concluded that all named categories of circularity should be used for the holistic calculation. In addition, it is important to create a common knowledge base in order to generate a uniform understanding of the criteria.

The next cluster of results relates to how building owners and investors would rank the various criteria of circularity, from the architects' point of view. For this purpose, the workshops proceeded analogously to the assessment of importance by architects. On average, the needs of the building owners were assessed in such a way that the Carbon Footprint and Material Health were the most important and Material Origin and Reversible Design the least important. However, the specific needs here also depend on the personal environment, the type of builder, and the project. It was mentioned several times that builders only want to integrate sustainability or recyclability into their projects up to a certain point, as long as it is economically viable. In many cases, the main incentive for builders as to why they support circular design is the subsequent sustainability certification of the building, which they can in turn use for marketing purposes.

One method that is becoming increasingly important in the planning field is Building Information Modeling (BIM), which enables an interdisciplinary exchange between specialist departments by linking various building model technologies and, by creating a digital twin of the building, providing the basis for analyzing the building's life cycle. Since current solutions for calculating circular buildings, require the use of BIM to some extent, the usage status of BIM was also queried for the analysis of the current state. During the workshops, it emerged that a large proportion of projects with a focus on sustainability are being planned in 3D and that there is a positive trend towards BIM use. Nevertheless, it is currently often the case that BIM is only used for internal purposes (especially in Germany) because it is not part of the tendered service for which the architect or planner is paid. The survey showed that almost half of the respondents use BIM in all their projects, but not from the beginning, but often only from the concept design phase or from the technical design phase.

In addition to the results of the workshops and the survey on the current situation, the following chapter presents the results of a market research in order to get an impression of which information sources and tools are currently available to planners.

## 4.3. Availability of information and tools for circular building design

The research has shown that a large number of sources are available, particularly in the area of pure information provision. A further distinction can be made between data platforms and (scientific) reports and studies. Data platforms contain information on components and materials that meet at least one of the criteria for circular construction, for example because they have a particularly low carbon footprint or a product consists exclusively of recycled materials. Examples of such databases include the Ökobaudat, the Materialbibliothek or the Milieudatabase. On these freely accessible material libraries, concrete and verified information about the ingredients is given, which can later be taken into account in the building design. In addition to the material libraries, there are many other sources of information online, with overviews and examples of how circular building can be implemented. In addition, scientific reports and studies provide background information on the circular economy and its implementation in the construction industry. All these can be used by planers to gather knowledge on circular construction and get inspiration on how to implement this to their projects.

One concept to be named is Level(s), which is a framework for sustainable buildings developed by the EU for public authorities, policy makers, architects, planners, engineers, building surveyors, investors and building users. The concept enables assessment and reporting of the sustainability performance of buildings throughout their life cycle. Greenhouse gas emissions are considered, as well as the origin of materials with a focus on resource efficiency. It also addresses material health, assesses the building's adaptation and resilience to climate change, and describes financial aspects.

In addition to the theoretical information gathering and the framework programs, there are also some tools and software solutions that can be used to plan circularly. In order to get a more detailed impression of some of these tools and software, a few of the programs are presented in more detail below with regard to functions for the holistic consideration and evaluation of circular construction.

OneClick LCA and Totem are calculation tools for performing a life cycle assessment (LCA): OneClick LCA is an LCA and EPD (environmental product declaration) software that enables the calculation of LCAs for subsequent certification under the most common certification systems. It is used for construction and infrastructure projects, as well as for product and company portfolios. Users, which include architects, consultants, engineers and building product manufacturers, require a license to access the web-based software. A data set can be imported from Excel, Revit, Tekla, Solibri or many other tools to create the LCA. The product focuses on calculating the carbon footprint, but does not consider any of the other components for calculating the overall circularity of construction projects. The second tool for LCA presented in this framework is Totem. This is a web-based calculation tool for assessing the environmental impact of buildings and building components over their entire life cycle. A comparison of different building solutions is possible. The planning tool is based on generic data and in part also enables product-specific EPDs. Via an import of an Excel file, the CO2 footprint can be calculated as a component of circular building design.

As pointed out earlier in this chapter, there are other criteria besides the determination of environmental impact that should be considered to determine the circularity of a building. For example, Aikana by Greenbimlabs is a software that can be used to evaluate buildings in terms of their circularity and material toxicity. It is also possible to obtain verified and detailed data on products and materials so that better insights can be gained into maintenance and demolition processes. In addition, lifecycle costing can be used to optimize expenditures and benefit from residual values. By importing a BIM model, it becomes possible to perform simulation and real-time optimization of safety, integrated into the work process. The tool is intended to serve as an intermediary between politicians, builders, planners and other parties. Since no specific information is provided on their website regarding the methodology of data collection or the approach to assessing circularity, it cannot be clearly determined at this point whether this is a holistic approach to determining the circularity of a construction project.

In addition to these tools, there is also the concept of material passports, which provides information about the material composition in a building. The idea behind this is to bring together and present all relevant information describing the properties and quality of a component or material. Material passports can either be processed manually with the help of a consulting company or software-based by uploading models. In order for a tool which is creating a material passport to be comprehensive, all phases of the life cycle should be included and both quantitative and qualitative information should be used. This requires a lot of different information to be compiled and linked to create a material passport.

Two example tools that have such a material passport as output are Madaster and Concular, which are briefly described below: The Madaster software allows a digital copy of a building to be created and a building resource passport to be produced from it based on a completed BIM model or Excel document. In the process, users (developers, planners, builders, consultants, certification service providers and many more) receive information on which components and materials can be found in which location in the building and what impact they have on the circular economy and environment. The components of circular building considered by Madaster are carbon footprint, separability of materials, material health, and recyclability. It is also possible to determine the building's residual value through the materials used. The second software is Concular, which is a tool for circular building used to record inventory, to mediate materials and to create life cycle assessments and material passports. It is used as a reporting, consulting and mediation tool by material seekers, deconstruction and demolition companies, planners as well as companies that want to buy back building materials. For a holistic view of circularity, this tool evaluates the carbon footprint, material recycling, material origin, Dismountability and Separability.

Besides these, there are only a few other software-based solutions for this topic and no standard. However, new developments are to be expected in the future, which will form the basis for the evaluation of urban mining approaches and facilitate sustainability assessments and certifications. For example, to date there are also no BIM plugins for creating a material passport. The use of a BIM model here has the advantage that a link between a physical element and a digital model can be created. Thanks to the availability of the corresponding data documents, the quality and reliability for reuse increase and thus form the basis for raising awareness to the topic of circularity.

Combining the findings from the workshops and the survey with the results of the market research, some problems arise for current tools: The survey found that current tools are often complicated to use, requiring a long learning curve. Furthermore, the user interface is designed in such a way that it is not adapted to the standard processes of planners. In addition, the processes in the tools are currently very decentralized and require manual input, which is due to the fact that a connection of the tool to the BIM model is often not possible or is not compatible with certain planning software. Further problems are that the data required for circular planning is not available, since no material libraries or product catalogs are linked and thus no concrete proposals are provided by the tool. In cases where such libraries of sustainability data on materials and products are available, planners are often unsure how valid and neutral they are. In addition, it was criticized that the calculation or evaluation of the circularity of a building project often takes place too late in the planning process, at a time when it is too late to make major changes. The market research and a literature search have shown that there are currently no BIM plugins for the creation of a material passport for the European region for the complete evaluation of the recyclability of a building.

## 4.4. Needs and requirements of planners for circular construction

Derived from the as-is situation, the resulting findings are presented in this chapter. Therefore, the needs of planners regarding circular construction are presented, resulting in concrete demands.

The first finding is that the majority of architectural firms currently do not have a concrete or consistent approach to integrating sustainability / recyclability into their projects. From this it can be concluded that the workflow is often uncoordinated, as circular construction is a new topic for which there is no standard process yet. Often, only large offices that are already heavily involved in the topic of sustainability have an internal competence team. Smaller companies often lack a standardized knowledge management system for the circular economy. From this, a concrete need for a coordinated process can be derived, which makes it possible to systematically integrate the circularity of a construction project into the planning.

The next finding is that the currently used tools for calculating the environmental impact of construction projects have problems in linking to the BIM model. Furthermore, different softwares cannot cooperate with each other, which would be necessary in the context of planning processes for the implementation of circular construction. In addition, available tools only cover parts of circular construction planning and often do not create a holistic picture. The resulting thesis is that there is no central tool that covers all sub-areas of circular planning without generating additional effort. The need of planners that arises from this is a way to do a holistic sustainability assessment that can be integrated into the usual process.

In addition, it has been found that the appropriate material libraries and product catalogs with valid information are often lacking for the assessment of the circularity of construction projects, which leads to the thesis that circular construction has implementation difficulties due to low data availability on materials and products. For a successful implementation of circular design, whether in the form of software or otherwise, sufficient valid data on the circularity of materials and building products must be available and easily accessible, for example in the form of a library.

With regard to the categories that are evaluated in a holistic view of circularity in the construction industry, it has emerged that the criteria are weighted individually and that this always depends on the person, the project and the environment. It can be concluded that it is necessary to use all categories equally for an overall calculation of circularity. Furthermore, all criteria should be explained neutrally so that a central knowledge base can be created.

Feedback from planners has shown that investors are often very open to most proposals for sustainable construction methods and often agree to this at the beginning of the project. Nevertheless, many of these proposals are not implemented later because they prove to be not very economical. From this it can be derived that an early concretization of the evaluation of the circularity of the building project simplifies the feasibility as well as the uniformity of the planning correctness. The need that arises from this is the possibility of carrying out the assessment at a time when far-reaching changes can still be made. This is possible, for example, if planners can provide their investors with comparisons of variants at an early stage. In addition, the sustainability assessment should be visualized in such a way that it is clear and can serve as a basis for decision-making. In this way, the possibility can arise to motivate the building owners and other stakeholders to more circular construction or to create awareness for it by facilitating communication.

## 4.5. Proposed solution for circular planning: BIM & More

Driven by the need of a tool that integrates circular planning directly into the BIM planning process of architects, EPEA decided together with Die Wekbank on developing a tool to solve this issue: BIM & More. Based on the results of the market research as well as the interviews, the tool can be optimally adapted to the needs of the users and meet their requirements. It enables an evaluation of the 6 criteria for circular building design - Carbon Footprint, Material Health, Material Origin, Material Recycling, Flexibility and Separability - for a building project and to do so in a coordinated, centralized process with early intervention options.

BIM & More is a system platform that allows manufacturers of building products and planners of construction projects to work together in a new way. On the one hand, manufacturers are able to connect their product data management systems directly to the BIM & More platform. This allows the provision of daily updated data and makes it available for all services that are connected to the BIM & More platform. On the other hand, planners and architects have the possibility to access this specific data of the manufacturers as well as to integrate generic data directly into their construction planning. For this purpose, BIM & More Metronome is designed as a conventional BIM library content management tool that allows planners and architects to organize industry product solutions as well as their own solutions in the backend. The integrated innovative BIM & More Plugin enables integration in Revit and Archicad. It works like other digital twin management systems, but with BIM & More it is also possible to calculate the circularity according to the Cradle to Cradle® design principle and life cycle assessments.

The focus of this review lies on BIM & More for Planners, which is intended to offer its users a variety of functions on two different interfaces that contribute to a circular planning process. The process that planners and architects go through in the tool on the two interfaces is very much based on planning processes common in the construction industry and expanded with aspects of circular building planning. At the same time, the process should remain individually adaptable to the project and the situation, so that it can be flexibly determined by the planning team.

At the beginning of the project, users already have access to a wide range of materials, objects and construction systems, which can be managed and created in company- and project-specific libraries, supplemented by their own components. Thereby, with the help of the tool, it is possible to optimize sustainability directly in the planning process and to obtain a sustainability certificate for each planning variant or stage. The calculation of the circularity and environmental impact happens at the material level, as this is the smallest scale. Each material provided in BIM & More has certain circularity values stored, which form the basis for calculating the circularity and environmental impact. This verification of the circularity information of materials and products is conducted by EPEA. Starting with the research project BAMB (buildings as material banks) in 2014, EPEA continued to collect and assess circularity data and now has been working with this data for years.

Now this data is no longer used only for consulting projects, but is made available to users as part of an comprehensive material library. The data is expanded with specific manufacturer data, who integrate their products into the planning processes of architects. These manufacturers and building material providers is given the opportunity to propose their products to planners directly in the BIM process as a suitable solution. On the other hand, the planners and building owners themselves also benefit, as they obtain information on recyclable building materials. The tool is therefore contributing to a positive Building Information Management which is intended to facilitate communication between the individual stakeholders.

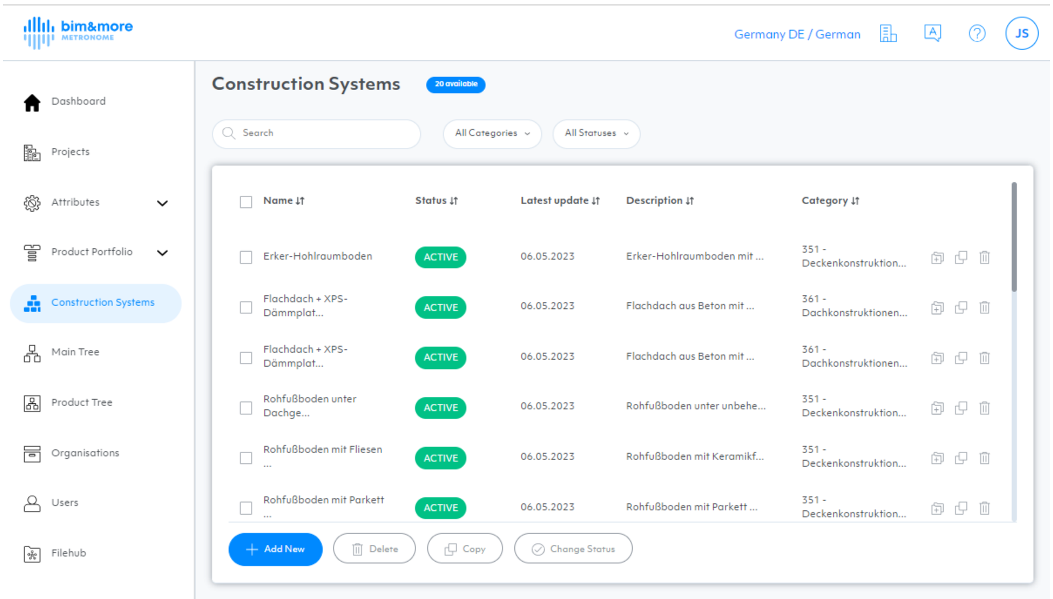



Figure 4 BIM & More - Library for Construction Systems – Source: BIM & More

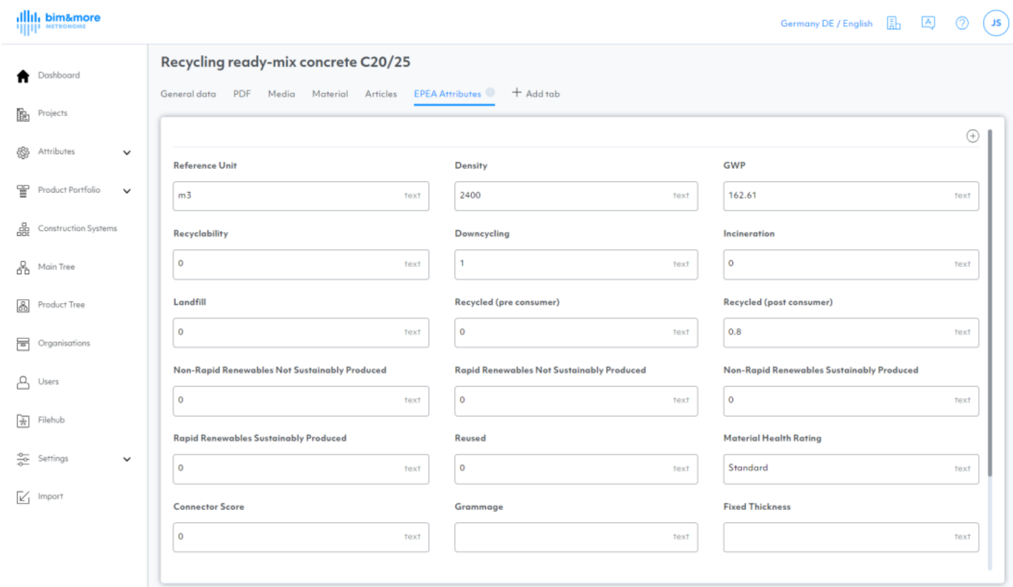



Figure 5 BIM & More - EPEA Attributes for Materials – Source: BIM & More

After the materials and construction systems have been organized on the online platform and compiled into a project-specific catalog, this catalog can be transferred to a BIM plugin. The plugin is integrated into one of several common CAD softwares and thus enables a direct link between the sustainability data from the project library and the BIM model. It is now possible to assign to the building model those materials and construction systems that are particularly well evaluated in terms of their circularity. It is also possible to display alternatives for these in order to be able to optimize them directly during planning. If an alternative component is selected in the plugin, this is also directly reflected in the digital twin. In addition, architects have the option of displaying the circularity status at any time during planning. This way, they are always aware of how the entire project is evaluated and for which sustainability criterion an improvement should still be made.

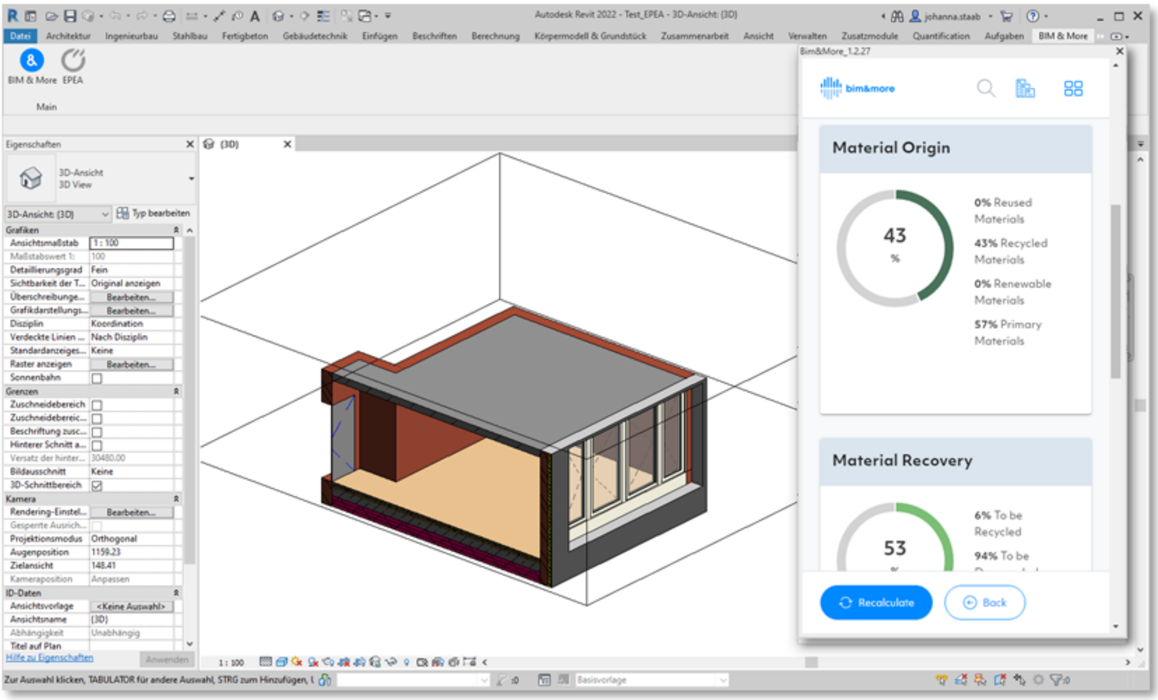



Figure 6 BIM & More - Project Evaluation in Plugin – Source: BIM & More

It is also possible to transfer this evaluation back to the online platform. This can be done either in the early planning phases or at the end of the planning process. In this way, other project participants, such as the building owner or sustainability consultants, have the opportunity to view the evaluation and make optimization requests without needing access to the plugin or having to perform an export. This visualization of the circularity from the start of the project serves as a decision-making aid and provides detailed information about which materials can be easily separated and the chemical composition of the products used. In addition, the status of material origin and recovery as well as the CO2 footprint can be analyzed and mapped. As a result the software is able to generate a circularity passport and thereby serves as an instrument for quality assurance by indicating which amount of the data consists of verified information.

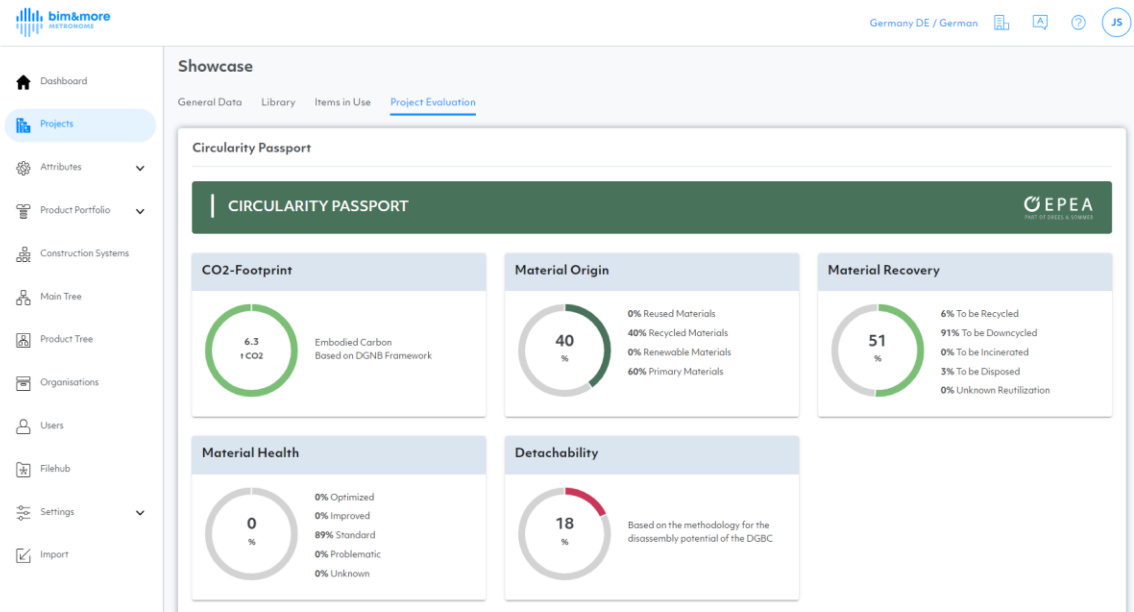



Figure 7 BIM & More - Project Evaluation in Metronome – Source: BIM & More

## Further needs

Some feedback that has been gained at the fair regarding functions and solutions have not yet been implemented, is the possibility to compare one's own project with other benchmark projects in order to see as of when one's own project is evaluated as particularly good or less good. In addition, the desire arose for a tool that makes it possible to evaluate existing buildings with regard to their circularity. Although this is possible with the tool, the registration of all materials and components used and the insertion of these into the BIM model is quite time-consuming and complex. In addition, there was a desire for a tool for circular urban planning, which also cannot be met by the software. For a holistic assessment and realistic implementation, it is also important to consider financial aspects, which can be used, for example, to determine the residual value of a building. Some of these needs for circular building planning, are partly covered by other software, as described above, or are currently not or hardly implemented. In addition to these findings on missing desired functions of the tool, there are further needs which refer to a higher scale. For example, an EU-

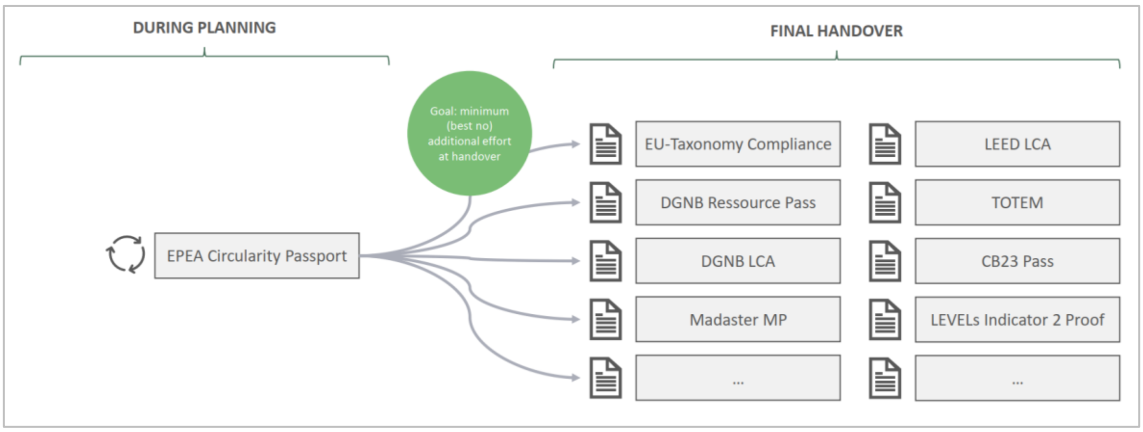



Figure 8: Envisioned solution for a tool that helps architects in handling different passport requirements.

wide harmonization of the assessment of recyclability is desirable, as well as a uniform regulation for BIM and IT structure in the real estate sector. In addition, a uniform database for generic materials should be made available at EU level, which could be integrated into such a software tool.

The goal of this software would be to provide architects with a solution that allows them to easily measure the most important metrics in a easily understandable format during planning. At handover the same methodology needs to be able to deliver all kinds of different passport formats that are already in place or currently emerging. It is obvious that to do that, more harmonization of the individual methodologies needs to happen. This harmonization will be further worked on within the remaining time of the ICEBERG project.

## 5. Conclusions

The fact that the construction industry consumes the most energy compared to other industries and produces very high CO2 emissions as well as a lot of waste calls for a rethinking and restructuring of the economic system in the construction industry. This process of change is supported by the rising amount of new legal directives on the level of the EU, the individual states as well as on a smaller municipal level. In this context, the EU Taxonomy is considered an important guideline, which provides a catalog of measures for politics and economy, which can result in an approach for the implementation of various sustainability topics, such as circular economy. The following activities of this and other guidelines are one step towards the transformation of a linear economy to a circular economy.

To this end, this report has shown that the circular economy, in comparison to the linear economy, is thought of in terms of circles, so that materials, after their initial extraction, theoretically circulate forever and are used again and again in other applications. To implement this, there are some principles that provide a guiding framework: For example, effective design enables pollution and waste to be avoided. It also aims to optimize the use of resources and promote the regeneration of natural systems. This leads to the maintenance and regeneration of the ecosystem, resulting in long-term economic recovery. One approach of circular economy is Cradle to Cradle, in which negative impacts are not only minimized, but additionally a positive added value is created, so that effectiveness and efficiency can be combined. In this framework, a biological and technical cycle are combined in such a way that they complement each other, resulting in an infinite use of a material. Applied to the construction industry, circular economy and cradle to cradle mean that building materials are less likely to be disposed or downcycled. Buildings are rather designed so that the parts in use can be removed in such a way that they can be recycled or reused in the same quality. Like this buildings serve a material banks for the future.

To achieve this, there are several criteria that should be considered in detail during the design of a building. These are interdependent in such a way that they contribute to a holistic circular building design. For example, the criterium material health determines how beneficial it is for human beings and the environment. As part of the analysis for material health, it is also determined how it is composed. Once the individual components are identified, it is easier to find out where they come from and to what extent they consist of recycled materials, for example. Thus, the analysis of one criterion conditions the other. From this, in turn, conclusions can be drawn for the CO2 footprint of the material, which are obtained from a Life Cycle Assessment. Material recovery provides information on how an individual material can be reused or recycled, which is directly dependent on its separability and flexibility.

In order to draw concrete conclusions for the implementation of this circular economy in the construction industry based on this basic knowledge, a market research was carried out within the scope of the study, as well as several workshops and surveys were conducted. From the findings on the current status of this, it was possible to determine the needs and concrete requirements of architects for a circular building design. The analysis of the status quo showed that it is necessary to evaluate the different criteria neutrally and to weight them equally, because both planners and clients evaluate the importance of these criteria individually, depending on the personal environment, the building project itself as well as the company. It is important to create a uniform knowledge base on which the common understanding for the implementation of CE can build on. It has also been found that most architectural firms do not follow a coordinated process to integrate CE into their projects, which requires a systematic and structured approach to its implementation. Furthermore, it can be concluded that there is a need of a common and process integrated solution for circular construction. This derives from the fact that cycle-enabled planning often cannot be integrated into the usual processes and that there are difficulties in linking the different tools. In addition, the availability of valid material and product data is necessary in this context, on the basis of which planning can be carried out. Information sources and tools that are currently used by planners are available in a variety of forms. Above all, platforms on which material knowledge and product information are available as well as studies on scientific sub-areas of the circular economy in the construction industry are available online. Software solutions offer the possibility to perform an LCA for a building, to create an EPD or to calculate and evaluate the circularity of a building. Some tools offer the possibility of generating a material passport from the data obtained, which can provide information about an overall overview of the circularity status. Problems that often occur with current tools, however, are that they are complicated to use or the evaluation of the circularity takes place only at a late stage of the planning process. Like this it is often too late to make far-reaching changes that generate a positive added value.

Based on these findings, EPEA has started to develop a software tool that tries to implement these needs. This makes it possible to integrate circular planning directly into the usual processes of architects. For this purpose, a two-part user interface offers the possibility of evaluating the circularity at an early stage of the project via a plugin in a planning software. On the other hand, valid material and product data can be used to carry out a pre-selection and pre-calculation right at the start, which is beneficial for building product manufacturers as well as for architects. The analysis of the circularity status of building as well as the possibility to compare project variants help reaching a uniform understanding of the project. By this the communication between all main stakeholders involved in building projects is facilitated.

The benefits provided by the proposed tool are the straightforward integration of circular design into the usual processes and the access to a material library including information on circularity. However, aspects such as the determination of residual value or other financial considerations or the handling of inventory are not taken into account. This shows that currently no software solution can cover all the needs of planners, which is related to the fact that circular economy is still a new topic in the construction industry. Entire processes have to be changed and intersections need to be revised. In an industry with such a complex product as a building and a complex stakeholder system this is just the beginning. Furthermore the implementation of an EU harmonization of ratings or the BIM an IT infrastructure as well as a common data basis for generic materials would create a better standard and facilitate the circular design process of building professionals.

In summary, it can be said that, derived from the environmental conditions and the new framework conditions, circular economy is already of high importance in the construction industry, but will become increasingly important in the future. However, for an easier and more standardized implementation, some adaptations to the needs of the respective planners have to be made. To meet these needs, information sources and the availability of valid data on recyclable products should be further expanded, and tools should be adapted in such a way that they can be integrated into planning by their users without additional effort.

## Literature and Online Sources

Bartels, Niels; Höper, Jannick; Theißen, Sebastian; Wimmer, Reinhard (2022): Anwendung der BIM-Methode im nachhaltigen Bauen. Status quo von Einsatzmöglichkeiten in der Praxis. 1. Auflage. Wiesbaden: Springer Fachmedien Wiesbaden GmbH; Springer Vieweg.

BCI (2023): online available via BCI | Every morning closer to a sustainable world (bcigebouw.nl)

Biomimicry 3.8 (02.11.2016): A conversation with author Janine Benyus; online available via: https://biomimicry.net/the-buzz/resources/conversation-author-janine-benyus/

BIM & More (2023). Online available via https://metronome.bim-more.com/ & BIM & More (bim-more.com)

Buildings as material banks (2023). Online available via BAMB - Buildings As Material Banks (BAMB2020) - BAMB

Braungart, Michael; McDonough, William (2021): Cradle to Cradle. Einfach intelligent produzieren. München: Piper.

Deutsche Gesellschaft für Nachhaltiges Bauen (2022): Detailanforderungen im Gebäuderessourcenpass. Online available via DGNB GRP 270722 Excel final.xlsx

Deutsche Gesellschaft für Nachhaltiges Bauen (2023): Gebäuderessourcenpass – Entwurf der DGNB. Online available via Gebäuderessourcenpass | DGNB

Ellen MacArthur Foundation (2015): Growth within: A circular economy vision for a competitive europe.

Ellen MacArthur Foundation (2017): Cities in the Circular Economy: An initial exploration.

Ellen MacArthur Foundation (2020): Material Circularity Indicator: Assessment tool for companies to improve product design and material procurement, Online available via https://www.ellenmacarthurfoundation.org/resources/apply/materialcircularity-indicator

Environment (2022) Level(s). Online available via https://environment.ec.europa.eu/topics/circular-economy/levels_en (Last access on December, 9th 2022).

EPEA (2022). Online available via https://epea.com/. (Last access on November 24th 2022).

Erkman, S. (2001): Industrial ecology: a new perspective on the future of the industrial system. In: Swiss medical weekly, 131 (37-38). ISSN 1424-7860. doi:10.4414/smw.2001.09845

EU Kommission (2019): LEVEL(S) - Taking action on the TOTAL impact of the construction sector. Online available via https://ec.europa.eu /environment/eussd/pdf/LEVEL(S)%20CONFERENCE%20REPORT.pdf , (Last access on December, 13th 2022).

EU Kommission (2022): EU taxonomy for sustainable activities. Online available via https://finance.ec.europa.eu/sustainable-finance/tools-and-standards/eu-taxonomy-sustainable-activities_en, (Last access on December, 9th 2022).

Europäisches Parlament und Rat (18.06.2020): Verordnung (EU) 2020/852 des Europäischen Parlaments und des Rates über die Errichtung eines Rahmens zur Erleichterung nachhaltiger Investitionen und zur Änderung der Verordnung (EU) 2019/2088. In: Amtsblatt der Europäischen Union.

GREENbimlabs (2021) [Online] (Last access on December, 9th 2022).

International Standardization Organization (2020): ISO 20887:2020 - Sustainability in buildings and civil engineering works — Design for disassembly and adaptability — Principles, requirements and guidance. Online available via (steelconstruct.com)

Madaster Germany (2022) Materialien Bauteile und Produkte. Online available via https://madaster.de/ (Last access on December, 9th 2022).

One Click LCA® software (2022) World's fastest Building Life Cycle Assessment software - One Click LCA [Online]. Online available via https://www.oneclicklca.com/ (Last access on December, 9th 2022).

Riba Architecture (2023): Riba Plan of Work (Image source). Online available via: RIBA Plan of Work (architecture.com).

Rommé, Jérôme (2022): Kreislaufwirtschaft – Circular Economy als nachhaltige, gesamtwirtschaftliche Produktion. Online available via https://www.dke.de/de/arbeitsfelder/components-technologies/circular-economy, (Last access on November 24th 2022).

Ruiz Durán, Christine; Lemaitre, Christine; Braune, Anna (2019): Circular Economy. Kreisläufe schließen, heißt zukunftsfähig sein. Deutsche Gesellschaft für nachhaltiges Bauen. Stuttgart. Online available via https://issuu.com/dgnb1/docs/dgnb_report_circular_economy?e=32742991%2F66977352.

Schäufele, J. (2021) „Concular - Zirkuläres Bauen - Marktführer für Materialpässe und die Wiedereinbringung von Materialien“, Concular - Zirkuläres Bauen, 21. April. Online available via https://concular.de/ (Last access on December, 9th 2022).

Stahel, W. R. (2010): The Performance Economy, Palgrave Macmillan UK, London, ISBN 978-1-349-28358-3.

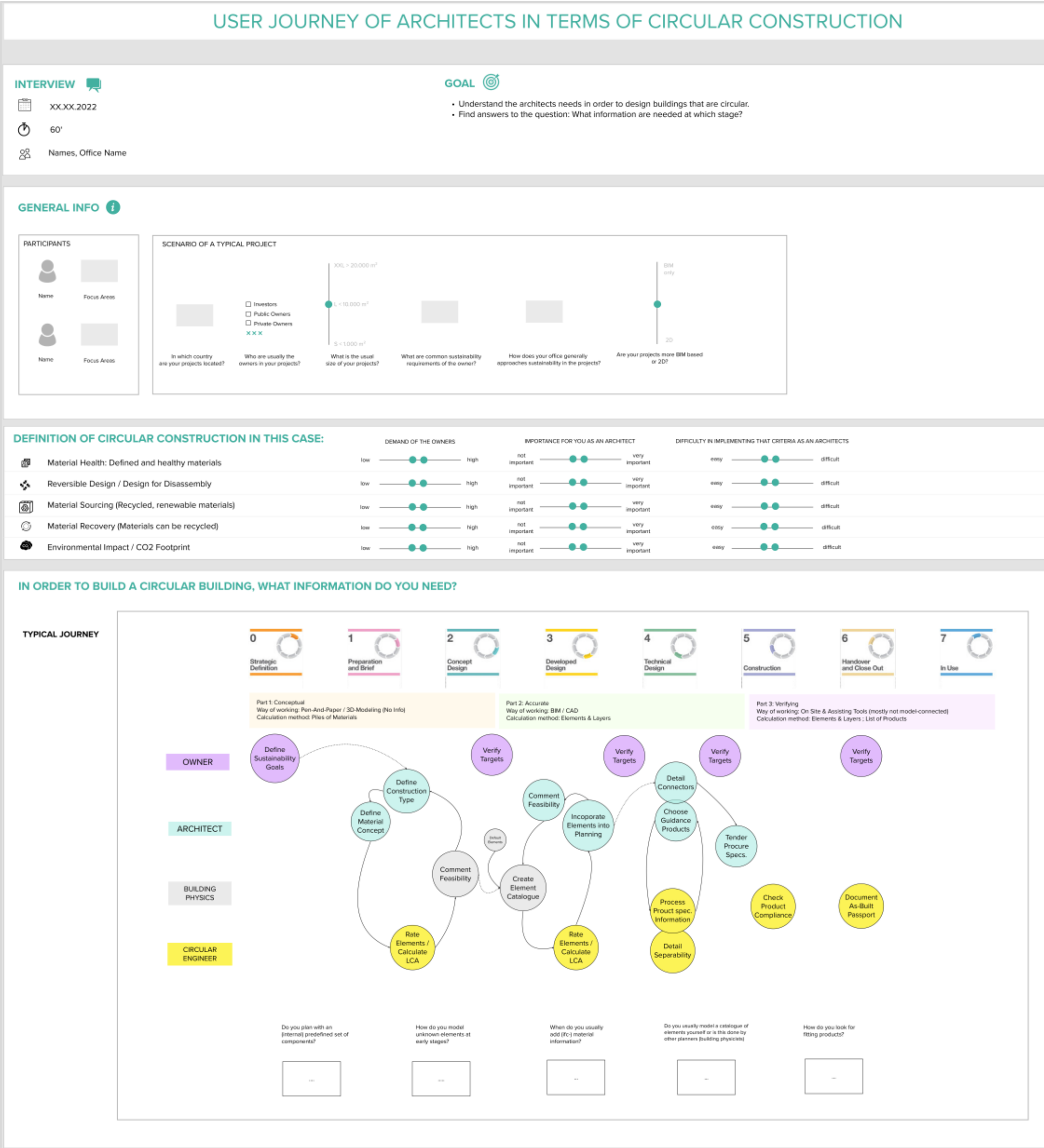
Thibaut Wautelet (2018): The Concept of Circular Economy: its Origins and its Evolution.

Totem (2022). Online available via https://www.totem-building.be/ (Last access on December, 9th 2022).

UN (2019): Global status report for buildings and construction. [Paris]: International Energy Agency; Global Alliance for Buildings and Construction.

Urban Mining Index (2023): Online available via: Urban Mining Index (urban-mining-index.de)

# Attachment 1: Template for online workshops with architects



# Attachment 2: List of questions from online survey

**Introduction Questions**

1) In which countries is your company located? (Please name 1 to 5 countries)
2) In which countries are your projects mostly located? (Please name 1 to 5 countries)
3) How many employees does your company have?
4) What is the usual size of your company´s projects?
5) Which Design Software(s) do you use?
6) What is your role within the company? What is your focus area within the projects you are working in?

**Circular Construction at your Company**

7) What role do sustainability and circular construction play in your company's projects?
8) Which criteria for Circular Construction are most important in your projects? Please rank the criteria in such a way that the most important element is at the top. (Possible solutions: Material Health, Reversible Designo r Design for Disassembly, Material Sourcing, Material Recovery, CO2 Footprint – all catagories where explained briefly in order to gain a common understanding)
9) Do you have additional criteria for Circular Construction, that is important to you? If yes, which?
10) What approach do you use to implement Circular Construction in your projects?

**Planning Process & BIM**

11) Do you have an internal template with a catalogue of predefined construction systems or products (integrated in your BIM software) that you plan with?
12) How do you search for material / product information?
13) In which project phase do you usually add material information to your BIM-Model (in case of BIM planning)?
14) Which amount of your projects is planned with BIM-Softwares (such as Revit or Archicad)?
15) At which project phases do you usually start using BIM? (not only 3D design but with information integrated)

**Software tool for circular construction**

16) Do you already use a software to calculate the environmental impact of your project work? If yes, which?
17) What problems do you see in these tools used? What do you miss?
18) What do you expect from a tool for calculating / visualizing circular buildings (eg. certain functions)?

**Closing questions 19 & 20**

# Attachment 3: Results of online research on information and tools on circular construction

| Title and description | Category | Short Link |
|---|---|---|
| Ökobaudat - Online platform of the German Federal Ministry of Housing, Urban Development and Construction | Information & Tool | Ökobaudat |
| Co2nstruction - Tool for calculation of CO2 footprint of building projects for verifiable and traceable sustainability | Tool | co2nstruction |
| Zirkuläres Bauen - Gebäudeforum Klimaneutral - Information on circular construction and C2C | Information | Gebäudeforum |
| Urban Mining Index - Calculation and Assesment of circularity rates within buildings | Information & Tool | Urban Mining Index |
| Circular Economy - Report by the German Sustainable Building Council (DGNB) on implementation of circular construction | Information | Circular Economy |
| Urban Mining Student Award - Contest that promotes circular building economy | Information | urbanminingstudent award |
| Materialbibliothek - Material database | Information | material-bibliothek |
| Circular Actions - Action plan with possibilities for design phase to realize circular economy | Information | ACTIONS \| Circular actions |
| Circle Economy - Consulting and information provision regarding implementation of circular economy & online tool for city scan | Information & Tool | Circle Economy |
| The Circularity Gap Report - Startegies and approaches on how to implement circular building | Information | Circularity Gap Report |
| Construction and Demolition waste: Challenges and opportunities in a circular economy - Background infromation on circular buildings | Information | Construction and Demolition Waste |
| The role of the client to enable circular economy - Report with results on a workshop with several players of the supply chain of a building project: What are the critical factors for implementing a circular economy | Information | Role of client in CE |
| Circular economy action plan of EU Commission - Background knowledgs on circular economy & list of online tools and studies for construction products | Information | Circular economy action plan |
| Levels - Methode for assessing sustainability performance | Information & Tool | Let's meet Level(s) (europa.eu) |
| RKW Architecture - Planning office that provides links to several tools and information pages regarding circular construction | Information | Nachhaltig Bauen \| RKW Architektur + |
| Green Bimlabs Research institute - Aikana as a tool for analysis an dprediction of circular construction | Information & Tool | Greenbimlab |
| Architects for future - Non-profit assosiation that wants to spread the idea and concepts of sustainable buildings | Information | Architects for Future |
| Concular - Tool for calculation parts of circular construction | Information & Tool | Concular |

| Title and description | Category | Short Link |
|---|---|---|
| Greengineers - Tool for calculation parts of circular construction | Information & Tool | Greengineers |
| Wecobis - Categorial information for building professionals | Information | WECOBIS |
| Fachagentur Nachwachsende Rohstoffe (Agency for Renewable Resources) - Information on renewable materials and building components | Information | FNR |
| One Click LCA - Tool for assessing circularity of building projects and components with focus on decarbonisation, reuse and recycleability | Tool | One Click LCA |
| Overview of Circular Buildings Toolkit - list of tools and infromation plattforms | Information & Links | ce-toolkit.dhub |
| Strategies and methods for implementing CE in construction activities in the Nordic countries – Study with supporting cases | Information | Strategies and methods for implementing CE in construction activities in the Nordic countries |
| Circular economy in the Nordic construction sector: Identification and assessment of potential policy instruments that can accelerate a transition toward a circular economy - report on potential policy instruments | Information | Circular economy in the Nordic construction sector |
| Circular Public Procurement in the Nordic Countries - Information on use of public procurement for construction materials and products | Information | Circular public procurement in the Nordic countries |
| Recycling in the Circular Economy - Report on how to improve the recycling markets for construction materials, biowaste, plastics and critical metals | Information & Tool | Recycling in the Circular Economy |
| Recyclability and reusability of key waste streams: PARADE. Best practices for Pre-demolition Audits ensuring high quality RAw materials - Information on the possibilities and requirements related to recycling and reuse | Information | Recyclability and reusability of key waste streams |
| TOTEM - Tool to Optimise the Total Environmental impact of Materials | Tool | TOTEM |
| The EU Building Stock Observatory - Tool for monitoring the energy performance of buildings | Information & Tool | EU Building Stock Observatory (europa.eu) |
| Resource efficiency in the building sector - Assesment of the environmental performance of buildings | Information | Sustainable buildings (europa.eu) |
| Framework for circular existing buildings - Circular indicators for BREEAM (NL) in use - Report on CE indicators for existing building and description of flows | Information | Framework-for-circular-existing-buildings_EN.pdf (figbc.fi) |
| The Circular Economya Powerful Force for Climate Mitigation - Report on Transformative innovation for prosperous and low-carbon industry | Infromation | The circular economy – a powerful force for climate mitigation |

| Title and description | Category | Short Link |
|---|---|---|
| Resource Efficient Use of Mixed WastesImproving management of construction and demolition waste - Report on C&D waste management including the identification of barriers and opportunities | Information | Report |
| RMIS - Database with raw materials | Information | Raw Materials Information System (europa.eu) |
| OVAM - Information an reports on circular economy and sustainability | Tool | OVAM |
| VUB: Circular Builidng Design - Design Tool on adaptable building | Tool | VUB |
| CB23 - Platform for circular design | Information | Portal Platform CB'23 (platformcb23.nl) |
| GRO - Design and assessement tool | Tool | GRO tool – GRO tool (gro-tool.be) |
| Statement from the Architects' Council of Europe - Report on Designing Buildings for Circular Economyt | Information | Statement from the Architects' Council of Europe |
| Statement from the Dutch Association of Architects | Information | Samen Circulair Ontwerpen & Bouwen (bna.nl) |
| Circular bouwen - van materialien tot bouwproject | Information | BVA / Actueel: Circulair bouwen |
| A framework for circular buildings - indicators for possible inclusion in BREEAM | Tool | A framework for circular buildings |
| Building circularity index - tool | Tool | BCI |
| ISO 20887:2020 - Iso Standard for sustaibability in buildings and civil engineering works - Design for disaassembly and adaptability - principles, requirements and guidance | Tool | ISO 20887:2020 |
| Milieudatabase - Dutch Environmental ormation Database with information on environmental performance of a building or an infrastructure project | Dataset | Milieudatabase |