MEANS-INSPIRED DESIGN

A design process proposal for a circular use of building materials

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ABSTRACT

Human behavior has since the industrial revolution had an enormous impact on climate, and the construction sector is a significant contributing factor. One possible way to reduce resource consumption and greenhouse gas emissions, would be to replace current linear economy systems with systems based on circular economy. For the construction sector, such a transition would imply building mainly with a circular use of building materials and products. Such a transition creates numerous challenges, not the least for architects who must adopt their design processes.

Design for a circular use of building components does occur to a small extent, but often with inefficient and unsystematic design processes. For architects to fully be able to design with already used components, the development of a structured design process is needed. Not much research has been done regarding circular building design, and even less which concerns how theory can be implemented in the every day design practice of architects. Therefore, this master thesis investigates how a design process could be modelled to support architects in designing for a circular use of building components. Through studying literature, through interviewing architects who work with circular design and through studying three different construction projects implementing circularity, deeper understanding has been reached regarding potentially necessary elements, usable tools and possible challenges that might be encountered during a such a design process.

Based on the research findings, a structure for a design process, with and for, reused components, has been developed as the main result of this thesis. The process can be used to guide architects who aim to design for circularity, with the aim to slightly reduce the gap between theory and implementation of circular economy principles in the construction sector.

Key words: circular economy, construction sector, circular building design.

STUDENT BACKGROUND

Bachelor Chalmers University of Technology

Master Architecture and Urban design,
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First year studios
Sustainable development and the design professions
Future visions for healthcare, housing and work
Managing design projects
History, theory and method: color and light
Spatial morphology

Second year studios
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Master thesis preparation course 2

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Relationship to topic

Since the beginning of my architecture studies at Chalmers, I have been interested in life-cycle aspects of design and the built environment. Building sustainably should not only be about how the buildings perform once in use, but also cover what happens before and after.

We have discussed sustainability questions in many different ways during my studies, but not much time has been spent exploring themes similar to circular economy, circular design and design for reuse. That is why I now would like to take the opportunity to learn more and to start to understand how these, often quite abstract theories can be translated to the actual design processes of architects.

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INTRODUCTION

PURPOSE AND EXPLORATION

Problem statement

Human impact on climate can no longer be denied, and the building industry has a large part in contributing to both increased emissions and exhaustion of natural resources (Esposito, Tse and Soufani, 2018). Globally, the building sector is responsible for about 33% of all emissions, uses 40% of all material resources and produces 40% of all waste (Ness and Xing, 2017). A shift in the building industry, from the current, linear economy system to a circular economy system could be one way to take greater responsibility for resource consumption and to respond to future sustainability challenges (European Commission, 2014). That would include a transition to building with products and materials that have already been used, which poses a great challenge for architects, who have to adopt their design processes to design for a circular use of building materials (Ali, 2017).

Designing for a circular use of building materials and components has become a frequently discussed topic on a conceptual level, but what is less explored is how such a design process actually can be translated into practice (Addis, 2006; Ali, 2017). As of today, circular design does occur, to a small extent, but with design processes that often are unsystematic and inefficient. To enable a wider establishment, a more structured design process must be developed.

Purpose and aim

The purpose of this thesis is to increase knowledge on circular economy and how its principles can be adopted by the building industry to reach a more sustainable use of resources. The aim is to propose a structure for a design process which supports architects in designing for a circular use of building materials and products.

Research question

How can architects change their design process to design for a circular use of building components, in order to increase circularity in the built environment?

Sub questions

1. What is circular economy and circular building design?

2. What challenges is the construction sector facing in adapting circular economy principles?

3. How can a design process be structured to support architects in designing for a circular use of building materials and products?

METHODS

Literature review

To get a better understanding of the complicated concepts of circular economy and circular design, and their many different aspects, an extensive literature review has been done, mainly in the beginning of the research process. Since the amount of research which could be found regarding circular building design specifically, is limited, literature on other, related themes were researched as well. Such themes were both the concept of circular economy in general, circular economy for the construction sector and general circular design. A majority of the studied material has had a theoretical theme, whilst only a few have been found that have connection to actual cases of implementation in practice. The literature have been found on Chalmers' architectural library, and in online databases; mainly Scopus, Google Scholar, and through BAMB (Buildings as Material Banks).

Interviews

A number of qualitative, semi-structured interviews have been conducted as a complement to the literature review. The main aim was to better understand implementation of circularity in building industry in practice and how it can effect the design process of architects. A contributing reason for performing the interviews were that little, architecture specific, written information regarding the topic was found during the literature review. The interviewees were architects who somehow work with circular design. A property manager, who works actively with strategies for implementation of CE was also interviewed. A majority of the interviewees have also had a connection to the case studies, in which cases, those projects have been discussed as well.

Case studies

For deeper understanding of the process behind designing for circular use of building components in construction projects, three specific design cases were studied and compared. The focus of the case studies has been the architects' design processes in terms of different approaches, strategies and design tools. To gather information regarding the case studies, different documents have been studied, such as pre-studies and early design proposals. Some of the interviews have also contributed with information.

Findings from both literature, interviews and case studies have been used to inform the proposal of the means-inspired design process, the result of this master thesis, which is presented in chapter four of this report.

DELIMITATIONS

The architect's perspective

For the background chapter, several different themes connected to circular economy, have been studied to gain better understanding of the complex concept. For the investigative parts of the thesis, the focus has been on the architect's perspective. Questions mainly connected to the perspectives of other involved stakeholders have not been explored in this thesis, even though they might of great importance for the implementation of circular economy. The aim has been to propose a process for general design for circular use of building components, which is why the proposed process has not been adopted to a certain form of contract.

Context

The background research context has been the western world and culture (with literature from European Union, United Kingdom and USA), since it to a large extent can be considered relevant for the Swedish context. The idea of this master thesis was inspired by Göteborgs Stad's aim to make the city more sustainable, through the initiative "Cirkulära Göteborg", aimed at increasing circularity within the city's construction sector. Therefore, the result of this thesis has been developed from a Gothenburg, and Swedish, perspective, to stay within the framework of current regulations, industry standards and pronounced circular economy directives. It has also effected the choice of interviewees and subjects for case studies.

Scales of circularity

Circular design can be divided into three different scales: macro- (society), meso- (building scale) and micro-scale (product). This thesis focuses on the meso- and micro scale, both in research and in the design process proposal, investigating circularity for buildings and their constituent components. Some elements included in the proposed process might however have connection to the macro scale as well, such as searching for used components from other buildings or from factories, but have only been added if of value also to the meso- and micro scale. During the case studies, more time was spent discussing the meso scale, since that is where the studies differ from each other. On the micro-level, few pronounced differences could be found.

Aspects of circular design

Circular design can be divided into three parts: (1) design for a circular use of components, (2) design for prolonged lifespans, and (3) design for an increased level of use. In this master thesis, the focus lies on the first part: designing for a circular use of components. In the design process developed as the main result of this thesis, some elements included have a connection to one of the other parts as well, but have been included only if being of importance for the main focus.

READING INSTRUCTIONS

This thesis is divided into five different chapters:

1. Introduction — Explains the framing of the thesis, through problem statement, research questions, methods, delimitations and a brief description of the project context.

2. Background — Presents the findings from the literature research which have been of importance for the development of the MID design process proposal.

3. Interviews & case studies — Describes the results from the interviews, followed by the information collected regarding the case studies.

4. Means-inspired design — Explains the means-inspired design process which is the main result of this thesis, based on the literature research, interviews and case studies. This chapter goes through the structure of the proposed process, step by step, explaining and commenting on its different elements.

5. Discussion — Elaborates on the thesis's result and how the means-inspired design process could be used as a tool by architects in their practice. Also discusses possible development of the tool, areas for future research, and how a transition to circular design could have effects on the role of architects.

GLOSSARY AND ABBREVIATIONS

Glossary

Circular economy	Circular economy is a system which aims towards eliminating waste by closing resource loops, through smarter design and through changing human consumption behavior, from a linear use of resources to a circular use.
Circular design	To design for circular economy by finding a way to offer a product (or a service) which is made from an optimal use of materials, is functional and delivers the best performance, while minimising negative environmental impacts along its whole life-span (Medkova and Fifield, 2016).
Circular building	A building that is designed, planned, built, operated, maintained, and deconstructed in a manner consistent with CE principles. (Pomponi and Moncaster, 2017).
Circularity	A collective word used in this thesis to describe circular activities, such as reuse or recycling, of materials or products. Circularity has in this text either been used when discussing all types of circular activities at once or when discussing circular activities in general, without wanting to define a specific type of circular activity.
(Building) component	The term building component is used in this thesis as a collective term for building materials (made from a single source) and building products (several materials joined together to make an object). In cases were only either materials or products are referred to, the specific word is used (material or product).

Abbreviations

CE	Circular Economy
CD	Circular Design
MOD	Means-oriented design, a design approach which departs from available means, which in a circular building context often refer to available building components.
GOD	Goal-oriented design, the more conventional design process of architects today, which starts with a defined goal, and all decisions that follow during the design process are made with respect to that goal.
MID	Means-inspired design, the design approached proposed as a result of this thesis.
LCA	Life Cycle Assessment (or Analysis), a method for assessing the total environmental impact of a product's during its full life cycle.
LCC	Life Cycle Cost, a method for analysing the overall costs of a product during its full life cycle.

PROJECT CONTEXT

Current situation

During the last 50 years, the global production of goods has doubled, and the amount of virgin material that has been extracted has tripled (European Environmental Agency, 2019). If human consumption behavior would continue on its current path, calculations show that the global demands for natural resources year 2030, would to be met, require two Earths, and by 2050 three Earths (Esposito et al., 2018). Water, food, energy and other fundamental resources are being jeopardised.

Linear economy

The linear system of resource consumption that modern society is based on was established during the industrial revolution (Andrews, 2015). It was further manifested when the concept of planned obsolescence was introduced to stimulate the market during the Great Depression in the 1930s (Moreno, De Los Rios, Rowe and Charnley, 2016). However, the rationing of products and resources during WWII forced people to care for the things they had through repair and reuse, so it was not until the 1950s that the idea of planned obsolescence was widely adopted. Products have since then been designed to quicker become obsolete, to create a pattern where products often need to be replaced, to increase company profits. Breaking this pattern of a linear "take-make-waste" system, which is so deeply integrated in the development of the consumer patterns and financial structures, policies and regulations of the modern world, pose an enormous challenge (World Economic Forum, 2014).

Circular economy

> *"A resource-limited world cannot afford to throwaway still usable resources, because of the environmental challenges, of the shortage of strategic materials as well as of lack of land for landfill and treatment purposes."*
>
> \- Ghisellini, Ripa, Ulgiati, 2018, p. 636.

The term 'circular economy' was first established in year 1989. A circular economy is according to World Economic Forum (2014, p. 13) "an industrial system that is restorative or regenerative by intention and design". It is a "regenerative production-consumption system that aims to maintain extraction rates of resources and generation rates of wastes and emissions under suitable values for planetary boundaries, through closing the system, reducing its size and maintaining the resources' value as long as possible within the system, mainly leaning on design and education" (Suárez-Eiroa, Fernández, Méndez-Martínez and Soto-Oñate, 2019, p. 958). CE aims to address the problem stated above, that a large part of humanity has developed a relationship to our planet and its resources, that is far from sustainable (Ness and Xing, 2017). It seeks to improve entire systems, instead of only maximising the potential of individual elements.

CE can be applied within all systems and scales - from industrial manufacturing and government organisation, to development of cities, or individual every-day life behavior (Ellen MacArthur Foundation, 2017). CE distinguishes between biological or technical nutrients and cycles (Ellen MacArthur Foundation, 2015). Only unharmful biological nutrients in unharmful amounts are allowed to be safely returned to the environment, while technical cycles are designed to keep its components within closed loops.

Defining sustainability

In the Brundtland report, United Nations (1987) define sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". During the development of the CE concept, its relationship to sustainable development has been frequently discussed. There seems to be many different interpretations, where the lack of a consensus regarding the definition of the CE concept itself further complicate the matter (Kirchherr et al., 2018). Some critique claim that circular economy does not address the social aspects of sustainability, but only cover ecological and economic aspects (Kirchherr, Reike and Hekkert, 2017). A few experts argue that sustainable development is a linear initiative, and thereby automatically would be a failure according to circular economy principles (Suárez-Eiroa et al., 2019). Most experts though, argue that the concepts of sustainability and circular economy are closely connected in either such a manner that circular economy is necessary for sustainable development, that circular economy is beneficial to sustainable development or that the two concepts have a compensatory relationship. How this potentially could be interpreted to the field of design is described by Sumter, Bakker and Balkenende (2018, p. 2) who write that "circular design can be considered as a part of design for sustainability with a number of more specific aims".

Challenges

Even though interest recently has increased significantly from several fields regarding CE, research on CE and strategies for its practical implementation are still in their infancy (Kirchherr et al., 2017). Potential reasons are the many barriers and challenges that hinder the realisation of circularity at a system level. Types of barriers range from being political, economical, technical and logistical, to being related to psychiatry and consumer behavior (European Environmental Agency, 2019). Successful implementation of CE principles would require fundamental changes at many levels, and by all stakeholders throughout value chains.

Circular initiatives

The transition to circularity is a complex process with no simple solutions, but there have been some important circular initiatives launched, such as the European Union and China adopting CE principles as part of their future strategies (Bocken, de Pauw, Bakker and van der Grinten, 2016). 1st of January, 2018, the new Swedish climate law regarding became effective, stating that a transition to CE is a prerequisite for reaching the international climate targets (SFS, 2017:720). On the local scale, initiatives like "Cirkulära Göteborg" question the current linear system.

Positioning

The construction sector represents a large part of humans' climate impact, and a transition to a more circular way of building could be one way to improve. That would however bring many challenges, the design process itself being one. That is way this master thesis aims to investigate how an architectural design process could be modelled to support architects in designing repeated use of building components, to contribute to increased circularity within the construction sector.

2.

BACKGROUND

CE IN BUILDING INDUSTRY

Current building industry

The construction sector is responsible for 40% of the global material consumption, making it the sector that consumes the most material of all (World Economic Forum, 2016). Globally, it contributes to about 33% of all emissions, with building constructions and demolitions potentially being the primary sources of solid waste worldwide, producing 40% of the world's yearly waste (Ali, 2017; Ness and Xing, 2017). In Europe, the building sector is responsible for 38% of the total waste production, 40% of the carbon dioxide emissions and uses 50% of all exhausted natural resources (Durmisevic, 2019). In Sweden, approximately 18% of greenhouse gas emissions are caused by the built environment (Boverket, 2018). A little bit less than half (46%) of those emissions are caused by construction, demolition and refurbishment.

Initiatives to make the construction sector more sustainable has traditionally been focusing on lowering energy use during the operational stage of buildings, while tending to ignore that what is done before and after the operational stages (e.g. construction and demolition) contribute to greenhouse gas emissions and degradation of our planet as well (Wijkman and Skånberg, 2015; Cheshire, 2016; Fouche and Crawford, 2017). In fact, research show that for modern, energy efficient, apartment buildings the relation between operational energy during use and embodied energy in the construction phase can be 50-50 (Femenías et al., 2018). The importance of the embodied energy is likely to increase in the future as the footprint of the operational energy decreases.

Commercial buildings are often demolished despite being in fine physical condition, for various reasons (Cheshire, 2016). Land values might have changed or the building might have served its original purpose and has thereby become obsolete. Premature refurbishments performed due to other reasons than wear and tear, done earlier than what material wear and tear would have required, are also commonly appearing, both within housing and commercial properties (Femenías et al., 2018; M. Enander, personal communication, February 26, 2020).

Current situation

Since the construction sector is responsible for such a large part of humans' negative impact on the planet, even small changes can contribute to major improvements (Pomponi and Moncaster, 2017). This has been acknowledged by many, for example the European Commission (2014), pointing out the construction sector as one of five prioritised areas in their Circular Economy action plan. In Sweden, several initiatives have been launched, supporting more circularity in the built environment. Boverket suggested in a report published 2014 that from year 2020, life cycle analysis (LCA, a tool for assessing the total environmental impact of a product through its life cycle) should be the starting point for assessment of construction, refurbishment and maintenance of buildings. Boverket (2018) are also currently formulating new regulations that will limit greenhouse gas emissions during construction. Since 2017, the Swedish Public Procurement Act approves that bids are compared to each other based on their lifecycle costs where costs of environmental impacts can be included, in contrast to only comparing investment costs (LOU 16 kap. 4 §). In January this year, Göteborgs stad published a report, investigating how to incorporate circularity in public procurement processes for construction- and demolition projects (Göteborgs Stad, 2020), an initiative that inspired this very thesis. In the recent years, major Swedish companies involved in construction have started to show interest in implementing CE ideas in their work (J. Nyström, personal communication, February 19, 2020). Change has been initiated, but nevertheless, it appears difficult to find completed buildings which have applied circularity to a larger extent and could serve as good examples for a more wide-scale implementation of CE in the built environment.

Academic research

Academic research regarding CE in the built environment has so far been rather limited to minimisation and recycling of construction- and demolition waste (Adams, Osmani, Thorpe and Thornback, 2017). Through the literature review done for this report, some research has also been found concerning barriers towards the implementation of CE in the built environment, models for decision-making, and platforms for sharing of information regarding buildings and building components. Several frameworks and tools for circular design have been developed through research but most of these seem fragmented, lacking important aspects and failing to cover the whole picture (van Stijn and Gruis, 2019).

Commonly agreed upon by academics is that CE can be implemented on three different levels: micro-, meso-, and macro level (Suárez-Eiroa et al., 2019). For the built environment, the macro level can be translated to a city or neighbourhood, the meso level to the building as an entity, and the micro level as a specific component or material. Some research has been conducted on the macro level, investigating for example eco-cities, and on micro level, exploring the circular economy for small-scale products (Pomponi and Moncaster, 2017). In comparison, the meso level has so far been less explored in research.

Circular building strategies

The overall goal of the construction sector shifting from linear economy to circular economy, is to maximise circular flows of natural resources and thereby reduce greenhouse gas emissions, pollution and waste to the largest possible extent, while increasing economic prosperity (Ghisellini, Ripa and Ulgiati, 2018; Ness and Xing, 2017). Pomponi and Moncaster (2017, p. 711) define circular buildings as "buildings that are designed, planned, built, operated, maintained, and deconstructed in a manner consistent with circular economy principles". In a report from the European Commission (2020), three main strategies for circular buildings are listed:

- Durability: encouraging a long term focus on the design life of building components.
- Adaptability: extending the service life of the building as a whole, with for example a focus on replacement and refurbishment.
- Reduce waste: design to produce less waste and for future circular use of building elements. Through component design and construction methods, promote reuse and high-quality recycling. Aim towards that most of the material value is retained at the end of a building's life-span.

Building with and for reuse

The least environmental impact would come from not building at all. The second best alternative is to build with components that have already entered the system, and to do so in manners that increase both durability and opportunities for adaptability. For the building industry to succeed with this, the circular use of material resources must become the standard solution, and the use of virgin material the exception (Göteborgs Stad, 2020). It will not suffice to only apply CE principles to new buildings, also existing building stock must be treated accordingly (Pomponi and Moncaster, 2017). By replacing parts of existing building stock (when it needs replacement) with circular building components, also already existing buildings will gradually become more circular (Van Stijn and Gruis, 2019).

Hierarchies

Circular use of building components already occur to some extent, but with a majority resulting in down-cycling where the value and qualities of components are reduced (Adams et al., 2017). The European Commission (2008) have published a hierarchy to support decisions that preserve component values, referred to as the 4R model (see fig. 1):

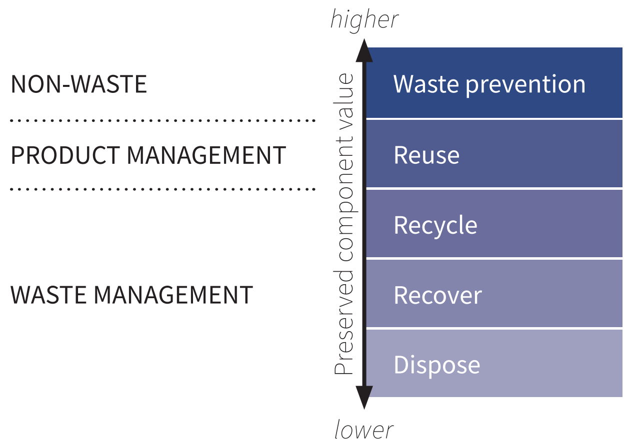


Figure 1. 4R model. Adapted from European Commission, 2008.

Over time, several new versions of the waste hierarchy have been developed to nuance the model for further inspiration on how to incorporate circular thinking. According to Kirchherr et al. (2017), the 9R model (proposed by Potting et al., 2017) is probably to most expanded version (see fig. 2):

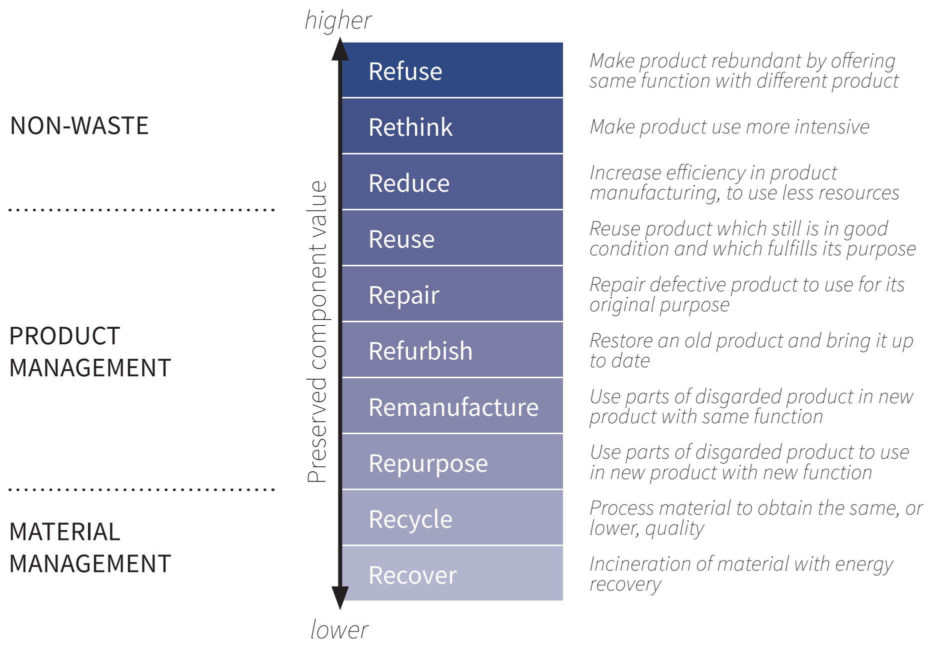


Figure 2. 9R model. Adapted from Potting, J., Hekkert, M., Worrell, E. and Hanemaaijer, A., 2017.

Reuse or recycle?

In both models, approaches such as 'reduce' or 'reuse', which require changes of entire systems, are clearly prioritised before 'recycling', an action which requires less change to current practices (Kirchherr et al., 2017). The hierarchies are in general not as often mentioned by practitioners discussing CE as by academics, a probable reason being that practitioners advocating for the implementation of CE fear that arguing for a more radical change might cause more resistance, a fear less common among academics. However, spreading the belief that only improving recycling is enough might lead to nothing more than continued unsustainable human behaviour. In an entirely circular building process, the amount of material that is recovered for energy or recycled should instead be minimised, while as many components as possible are directly reused (Göteborgs Stad, 2019b).

The hierarchic models give a general order of priority for how to approach circular component flows, but the specifics of each case must be individually considered to be able to make the most suitable choices (Göteborgs Stad, 2019b). Not only the characteristics of a certain object must be taken into account, but also other factors related to it. The diagram in figure 3 attempts to map important aspects to consider, to give an insight into the complexity of choices to be made, when building according to CE:

Material parameters

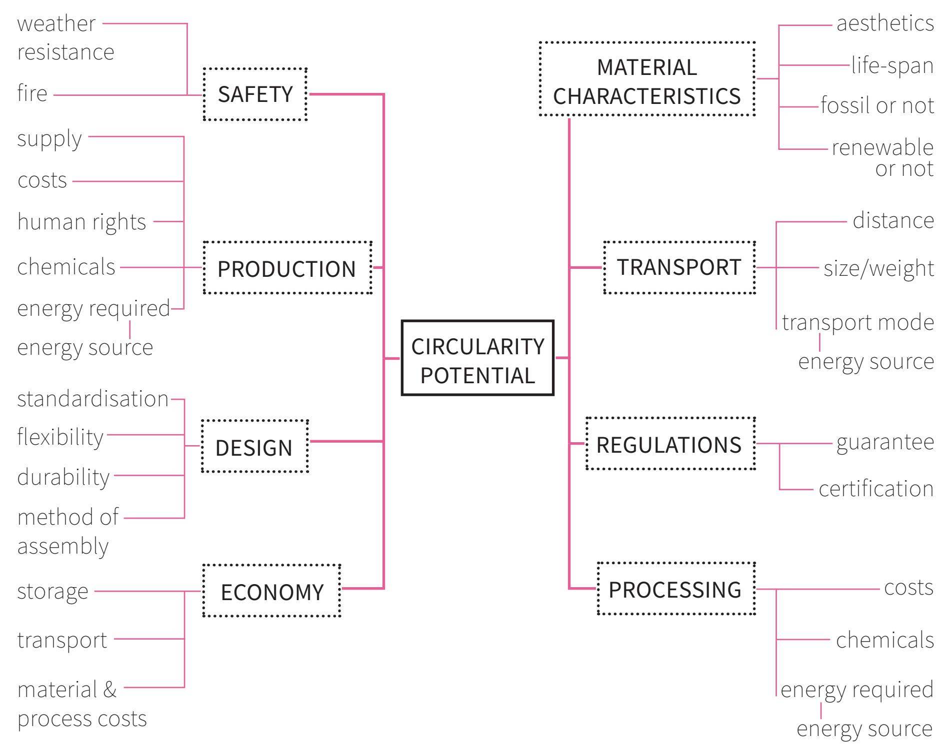


Figure 3. Some aspects to consider when evaluating circular potential of building components

By making conscious choices, it is possible to maximise the potential for circularity in the built environment. Some materials commonly used in buildings, like steel or wood, have long lifespans and are fairly easy to process, and might therefore be more suited for reuse (White Research Lab, 2019). On the contrary, other materials might be difficult to reuse but easier to recycle. The earlier on in a project that these kinds of considerations are involved, the more resources can be saved even before construction, and a larger part of the material that is actually used, will later be reusable (see figure 4).

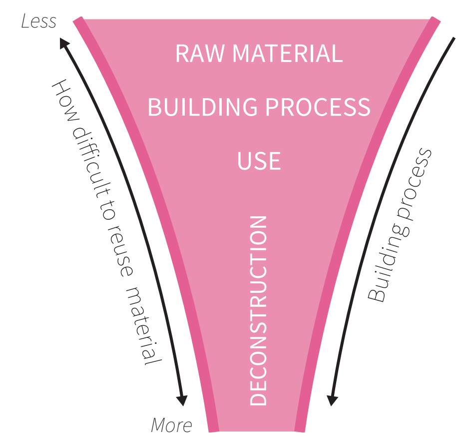


Figure 4. Potential for material recycling for different phases of the construction process. Adapted from Göteborgs stad, 2019b.

When comparing components, consideration also needs to be given to the purpose of the specific design. Although a building in general have a longer life-span than many other man-made products, and even though prolonged life-spans is generally strived for according to the CE, some of the components of which a building consists might be replaced with shorter intervals (Cheshire, 2016). There are also cases where a whole building is supposed to be temporary. En example is the People's Pavillion that was assembled for the Dutch design week 2017 in Eindhoven (White Research Lab, 2019). All its parts were borrowed, and the main priority was to use methods of assembling that ensured that the parts could be returned to their owners in unchanged conditions, when the event was over. So even if long durability often is a priority in circular design, there are exceptions where other aspects might be of higher value.

Barriers

The challenges the building industry face in adopting CE principles on a system level are many, of different characters, and often interdependent. The following episodes seek to give an overview of some of the most commonly discussed barriers and challenges the building industry faces.

Knowledge and tools

Different tools for evaluating and comparing material alternatives have been developed to aid in making the complicated decisions often faced in circular building projects, but so far the knowledge and experience of circularity within construction is very limited (Ghaffar, Burman and Braimah, 2020). Recurrently mentioned tools in circular building contexts are Life Cycle Assessment (LCA, analysing the overall environmental impact of a product during its lifetime) and Life Cycle Cost (LCC, analysing the overall costs of a product during its lifetime) (Ghisellini et al., 2018). The tools can however be difficult to use during early stages of a design process since quite detailed information is needed to perform the calculations, often more detailed than what the design actually is in early stages (Olsson, Westin and Marsh, 2019). Due to this, LCC and LCA calculations often end up being used to confirm a design when it is almost finalised, rather than as a tool for design development. Another issue is that the tools can be applied to different extent, from analysis being limited to the construction site and waste disposal, to also covering the production phases of different involved materials (Ghisellini et al., 2018).

Another type of tool that needs to be developed for CE implementation is a tool that can be used to gather and share component information (GXN, 2018). To enable future circular use of building components, their characteristics, condition and qualities need to be known. This knowledge must be stored, kept and available for all stakeholders that are, and will be, connected to it. These types of tools are often referred to as material passports, or material IDs. For a while, there has been development of databases to fulfill the purpose, by using, for instance, BIM (Building Information Modeling) (Ali, 2017).

Economic aspects

LCC calculations, with the purpose of calculating the costs of a building over its life-span, are still not performed very often, despite being useful for creating a more holistic picture of a construction project (Boverket, 2018). Except for a lack of knowledge on how exactly to perform LCC calculations in reality, another contributing factor that has been suggested is that many clients and decision-makers lack long-term perspectives (Göteborgs stad, 2019a). Short-term economic benefits are chosen over long-term wins, resulting in that solutions, which would have been more economically and ecologically sustainable over time, often are ignored. Introducing financial incentives to make reusable choices less expensive than unsustainable alternatives could help accelerating the transition towards a circular building industry (Kirchherr et al., 2018).

For it to become financially sustainable to build with a circular use of components, more large-scale marketplaces are needed where it is easy to buy and sell already used components (Göteborgs Stad, 2020). It must be possible to trust that when times has come to start the construction of a building, the components that are needed can be found, without becoming excessively expensive or time-demanding (M. Enander, personal communication, February 26, 2020).

Organisational aspects

For a circular use of building parts to become widely established, new models are needed for allocating long-term economic and juridical responsibilities for the elements of which a building consists (Göteborgs stad, 2019b). How to store components between uses also pose a challenge. A potential system is that the responsibility of a certain component could remain with the manufacturer even though the component (temporarily) has become part of a building. When the component needs to be serviced or replaced, the manufacturer provides that. If the building is demounted, the manufacturer cares for the product before it is given its new purpose.

Common bureaucratic arrangements regarding responsibilities and sharing of information between different stakeholders of construction projects often complicate dialogue within and between projects (Boverket, 2018). Taking part of each other's knowledge and learning from earlier experiences becomes more difficult. Issues regarding communication between different stakeholders also obstruct sharing of building component information between parties, and over time (IVL, 2018). Overcoming this obstacle is a prerequisite for a circular building industry.

Legislative aspects

Current systems for certification and classification of building components, regarding for example fire safety, are often mentioned as hindering circular use of building parts. Some argue that not being able to guarantee the state of a certain component, which has already been used, poses a considerable barrier (Ghaffar et al., 2020). Others argue for a different point of view, pointing out that, for example, not all doors in a building are likely to have the same fire safety demands, since not all have to create fire cells (A. Höjer, personal communication, February 26, 2020). The second approach might not lead to a building that is made entirely from reused components, but it might contribute to circular development getting somewhat further.

Preconditions for a circular building industry

To conclude, the challenges that need to be met are many. Göteborgs stad (2020), have listed ten preconditions, that need to be fulfilled in order to achieve a circular construction sector (see figure 5 below).

Figure 5. Ten preconditions for a circular construction sector. Adapted from Göteborgs Stad, 2020.

Several of these have been discussed in this chapter. The following chapter will explore precondition no. 3 - design for circularity, the precondition that may have the strongest connection to the role of architects.

CIRCULAR BUILDING DESIGN

The importance of design

A few studies have been done investigating barriers and prerequisites for the implementation of CE in the construction sector. They seem to agree that design is of great importance for the circular potential created (Göteborgs stad, 2020; European Commission, 2020). This also seems to correspond with the opinions presented during the interviews done as part of the research for this report, with different representatives from the construction sector.

Current situation

There are some architectural offices that have incorporated CE principles in their design work, but lack of guidance and well-developed design tools, such as platforms for material comparison, is holding back a broader, system-level implementation (Ali, 2019). Additional research point to other areas of knowledge that need to be expanded upon regarding circular building design, from deeper understanding of building materials, to better understanding of social behavior (De Los Rios and Charnley, 2017). Also relevant is that even CE research themes that have been more widely explored for building construction in general, such as waste management, rarely cover the roles of architects and design to any greater extent, despite the great influence design is claimed to have on the circularity potential (Ali, 2019).

Circular design strategies

Ellen MacArthur Foundation (2015) suggest that to create functioning circular material flows, one should differentiate between technical and biological cycles (see figure 6). Technical products should be designed to be kept in circulation, contributing to economic yield. Biological nutrients are instead allowed to be safely returned to the biosphere when they have served their full purpose, to become feedstock for new cycles.

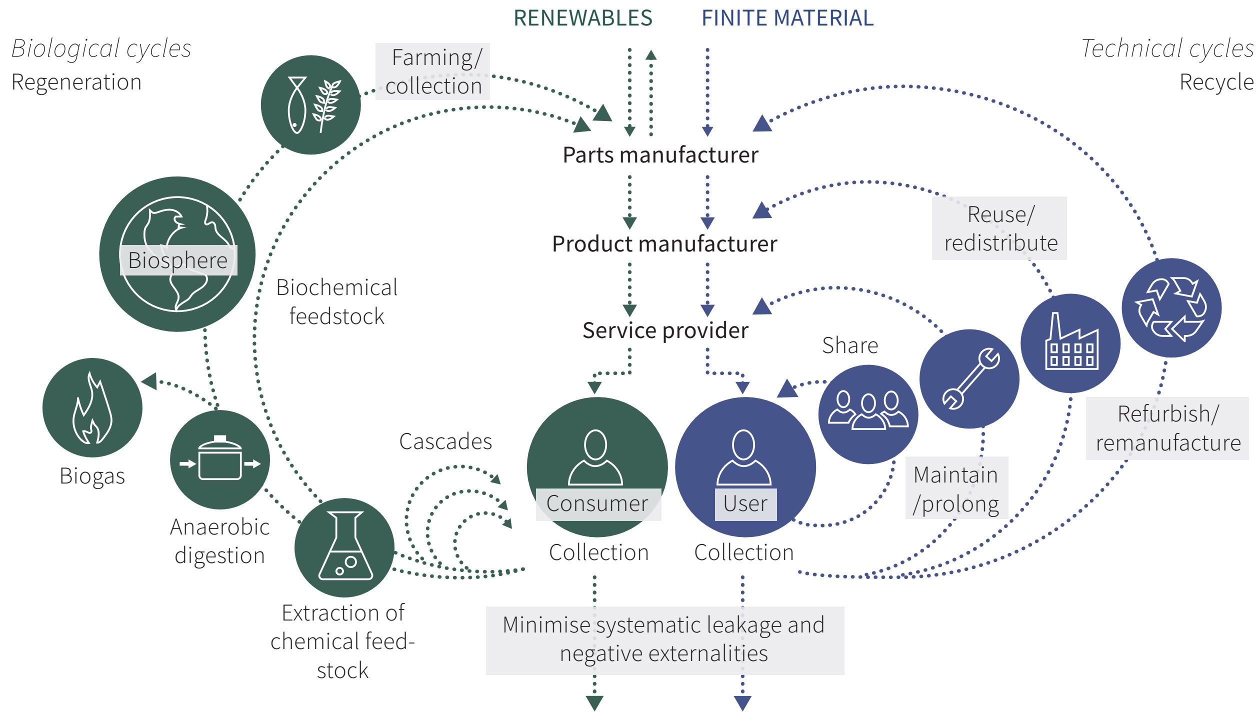


Figure 6. Biological and technical cycles. Adapted from Ellen MacArthur Foundation, 2015.

This offers some similarities to the work of Bocken et al. (2016), who have elaborated on different strategies for creating a circular use of resources that enter consumption systems. They as well list designing for a technical cycle and designing for a biological cycle, but add a third strategy: designing for dis- and reassembly. The strategies can be applied both when designing with components that are already in use and with virgin materials. It is however important to keep in mind that some components of the current building stock contain harmful substances and might therefore not be suitable to reuse (J. Nyström, personal communication, February 19, 2020). Both Bocken et al., (2016) and Ellen MacArthur Foundation (2015) concern design in general but seem to be supporting building design as well.

For buildings specifically, inspired by Duffy and Brand (1994), GXN (2018), explain their strategy to consider the building as made up of layers with different life-spans and different needs for maintenance and repairs (see figure 7). By creating a design that allows the different layers to be repaired or remade at different occasions, future circularity is enabled.

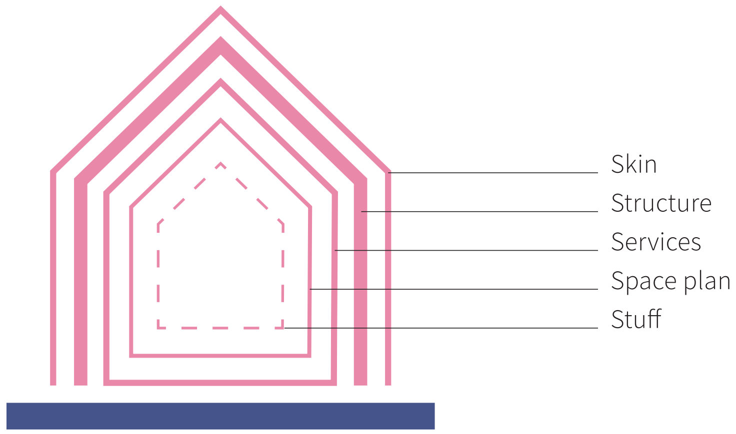


Figure 7. The main layers of a circular building design. Adapted from Brand, 1994.

To do circular design

Circular design requires decisions tailor made for each case, where consideration is given to the specific circumstances. Guiding hierarchies have however been published, which can be used for general advice on how to prioritise in a circular design process. The figures 8a and b, display the hierarchies of circularity strategies, which were published by White research lab (2019) and Göteborgs stad (2020). How the varying choices of types of reuse and recycling are ranked show some connections to the 4R and 9R waste hierarchies (see figures 1 and 2 on pp. 17-18), all aiming towards maintaining or increasing component values.

1	Reuse of floor plan - reuse existing plan and structure. *meso scale*
2	Reuse of building parts on site - reuse what is already in the project. *meso scale*
3	Reuse of building parts from other site - from nearby projects or from a vendor. *meso scale*
4	Upcycling - use discarded objects for new purposes. *micro scale*
5	Rent/lease - the supplier is responsible for products through circular loops. *micro scale*
6	Buy new - plan for long product life and prepare for reuse. *micro scale*

Figure 8a. Circularity hierarchy. White Research Lab, 2019

1	Reused products which can be reused again after being used and disassembled. *micro scale*
2	Reused products. *micro scale*
3	Products with high proportion of recycled material, which can be reused or recycled again. *micro scale*
4	Products of virgin material, which can be reused several times in the future. *micro scale*
5	Products of virgin material, where material can be recovered with high efficiency. *micro scale*
6	Products of virgin material, which can not be recovered and should be avoided.

Figure 8b. Circularity hierarchy. Göteborgs stad, 2020.

Both lists have been produced specifically for the built environment but appear to have different scales in focus. The list by Göteborgs stad (2020) seem to explore the micro level of a building, focusing on the treatment of building parts as separate entities. The list by White Research Lab (2019) could be interpreted as at least partly focusing on the meso level - the building as a an entity, a linked system. made up of several constituent components. The list from Göteborgs stad, has a more clearly outspoken focus on the importance of potential future cycles, which in the White Research Lab hierarchy is clear only in the two bottom categories. Both lists could probably be useful, but in different situations, when designing an entirely circular building.

A new role for architects

A subject often debated when discussing the building industry's adoption of CE principles, are what new roles and responsibilities it might imply for different stakeholders. For architects, a potential new role could be as pioneer, guiding clients towards circularity (Sherwin, 2018). Innovative thinking, suggesting novel solutions and assisting clients in evaluating their organisations are other possible responsibilities (N. Wolf, personal communication, February 7, 2020). Connected skills that might need to be developed are to design for flexibility and adaptability, and to become better at identifying new possibilities of (shared) use in existing spaces.

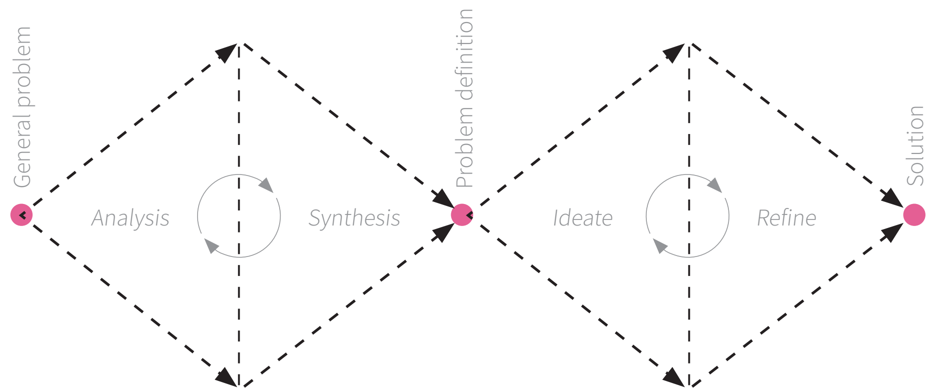
Architects have traditionally been focused on the creation and construction of buildings, spending less time considering deconstruction and unbuilding (Ali, 2019). Learning to design according to circular economy principles impose new requirements on designers, who have to learn to become system thinkers (Moreno et al., 2016). To do circular design is to design with and for reuse, which requires adaptations of the design process, as compared to designing with virgin materials. Architects learning that to a larger extent base their design on what is available, is a prerequisite for circularity within the built environment (Ghaffar et al., 2020; Göteborgs stad, 2020). This requires both new methods, and a change of mindset, learning to see new potentials in already used components.

MEANS-ORIENTED DESIGN

Means- or goal-oriented

Circular design is a complex task that involves the understanding of many areas of knowledge. According to Bill Addis (2006), it also requires a design process that in many ways is entirely different from conventional processes used by architects and designers. The way of describing a design process as either means-, or goal-oriented, as established by de Jong & van der Voordt (2002), can be used to categorise the methodologies used for conventional and for circular design. The conventional, goal-oriented design (GOD) starts with a defined goal (requirements for a building design to fulfill, for example), and all decisions during the process are made with respect to that goal. The means-oriented design (MOD) process has its start in the limited means available (for example building components), which guide the end result with, from the start, less defined goals. Both design processes can be used on different scales, from smaller products to urban scale projects (Pereira, Datta and Mancini, 2016). No design process is entirely means- or goal-oriented, but has some elements of each type of process and can be dominated by one orientation (de Jong & van der Voordt, 2002).

Little research can be found exploring the concept of means-oriented design. Among the limited information found regarding MOD processes, Pereira et al. (2016), have in figure 9 compared the structure of a MOD process to a GOD process, which can give a rough overview of their different constituent elements:



	DISCOVER	DEFINE	DEVELOP	DELIVER
Means-oriented design	• Identifying components available • Initial research: circular use • Task: find destination	• Component learning • Brainstorming • Concepts development • Outline design • Preliminary documentation	• Detail design • Specification • Refurbish/ recondition • Design testing • Documentation • Redesign	• Redesign • Find alternatives • Specification • Construction
Goal-oriented design	• Identify user need • Initial research: market and/or user research • Task: meet users' needs	• Define priorities • Brainstorming • Concepts development • Outline design • Preliminary documentation	• Detail design • Specification • Component selection • Purchasing components • Documentation	• Construction

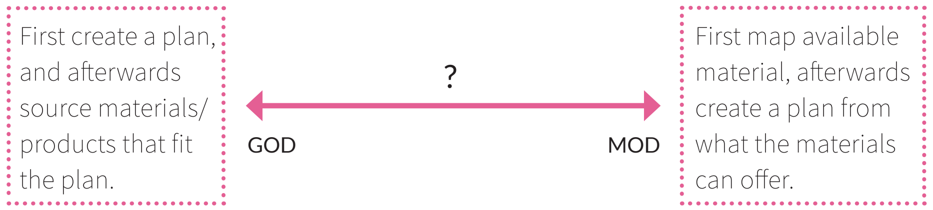
Figure 9. Comparison of MOD and GOD processes. Adapted from Pereira et al., 2016.

Acquiring materials

How newly-produced components are acquired within a GOD process is well established, according to Pereira et al. (2016). In many cases, components are determined based on local availability, cost, and current practice, as well as the designer's background, knowledge and experience. It can also be guided by a stakeholder's interest or by standardisation. Marketplaces where the components can be bought are in most cases known. When trying to choose already used components in a GOD process, no corresponding markets exist. On the contrary, when components are established as a first step, as in a MOD process, they instead need to be contextualised. However, attempts to apply MOD processes often fall short, due to a lack of an established structure for such a design process.

Finding a balance

As de Jong & van der Voordt (2002) states, no design process is purely either means- or goal-oriented. Neither is it common that architects work in design projects that are entirely open-ended, in such a manner that no predefined goals exist. In most cases, there are preconditions to fulfill, which can be questioned but rarely ignored, such as functional requirements from clients, or parameters controlled by the detailed development plan. That in itself can be contradictory to the core idea of the MOD process and raises the question of how architects could, if it is true that a more means-oriented design process is crucial for circular design, adapt their design processes without loosing the ability to relate to certain preconditions. How could a design process be structured to support architects in designing for a circular use of building components, by finding a balance between considering components available and set preconditions?



SUMMARY OF CHAPTER

CE in building industry

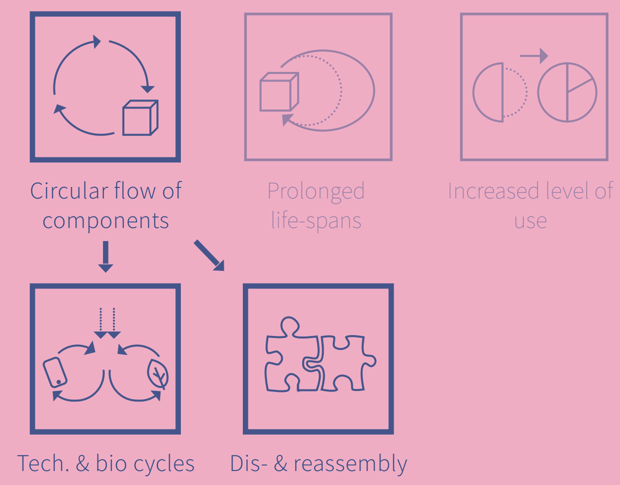
The construction sector has traditionally focused on energy efficiency and climate actions during the operational stages of buildings, but has now understood the need to also reduce negative climate impacts from construction- and demolition processes. A theory which approaches this issue is circular economy (CE), and since the construction sector constitutes a large part of human's total ecological footprint, its adoption of CE principles is frequently debated. However, the implementation of CE in the construction sector faces many different challenges.

Circular building design

A significant part of a building's footprint is dependent on decisions made during the design phase. Circular building design, to design buildings for circular economy, can be summarised to three main parts - designing for a circular use of building components, designing for prolonged lifespans, and designing for increased level of use. This master thesis focuses on the first part - design for a circular use of building components. Strategies which can be used to achieve this are to separate technical and biological material flows and to design for dis- and reassembly. Circular building design currently occur to a small extent, but these processes are often unstructured and unsystematic, which often leads to inefficiency, and sometimes even failure in proposing relevant design.

Main parts of circular design

Circular flow strategies



Means-oriented design

Some research claim that to be able to design for a circular use of building components, architects must adapt their process so that its starts in what the available components, and to let these guide the design process towards a, from the start, less defined goal. This has been called a means-oriented design process (MOD), as compared to the today more common, goal-oriented design process (GOD). How the two design approaches differ, can be described as either ranking materials after how well they fulfill certain, already set, requirements (GOD), or as ranking different uses after how well they would exploit a component's full potential (MOD). There is however a lack of knowledge among architects of how to do means-oriented design for circularity purposes, how to structure such a process and what methods that could be used. Neither has it been developed how a MOD process could be used within the types of preconditions that many building design projects face, such as limited budgets, time frames or already set aims with the design.

3A.

INTERVIEWS

Interview process

Several interviews were held with architects that in different ways have experience from working with circular design in the Gothenburg area. Some of them have a connection to the initiative “Cirkulära Göteborg”.

The interviews were semi-structured, but all interviewees were asked the same primary questions, which have been listed in the appendix. The focus of the interviews were on the interviewees’ experiences of working with circular design, what challenges they have encountered in different circular design projects and important learnings from these.

The interview answers have mainly been analysed and compared based on the following themes:

- Working with circular design as an architect.
- How, and what, information to gather when working as an architect with circularity in building design.
- Encountered challenges.
- Tips (approaches, methods and tools which they have found useful in their practice).

Learnings from the interviews have been used to build the means-inspired design process, contributing with methods and tools, and their insights and experiences have for example affected the order of activities in the MID process.

Interview with JENNY NYSTRÖM

Architect at Kjellgren Kaminsky.
Has been writing reports and creating guidelines for Cirkulära Göteborg, regarding how to achieve increased circularity in the built environment. She has also been involved in design projects with reused interiors.

To do circular design

Jenny points to the importance of architects rethinking how they design, in order to be able to do circular design. Some things are designed in a certain way just because it is how it usually has been done, without considering all consequences of the design. One aspect architects should always consider when doing circular design it the possibility for disassembly. Architects working with already used materials might also have to avoid working with exactness in drawings. In cases where not all components are known during the design process, but instead will be acquired later, having traditional drawings with exact measurements, might automatically exclude used components that in reality would have worked well to use again. This might require alternative ways of communicating design decisions, and some of the decisions might also have to be made at the building site. In that case, the architects have be more present at the building site.

Gathering information

To enable circular use of a component, information regarding its classification and certification must be known, for example related to noise reduction or fire safety. It is also important to figure out if the classification still would be valid if the component is moved, altered or treated a certain way.

Challenges

A challenge for architects is to find information on how to actually do CD, despite the fact that many documents, there among Gothenburg's vision document, state that the construction sector should implement more circularity. Many industry standards, regarding for example how to construct a certain wall, advocate for using glue, which suggests that the visions have not yet been fully implemented. Questioning those standards is important. Other challenges are connected to new methods which will be needed to communicate design. For example how to apply for a building permit, or how to discuss the design with other stakeholders, when not all parts of the design are known.

Tips

- Have standard component measurements in mind to a larger extent when designing, and be smart. Make conscious decisions to avoid having to throw away unused material only due to design.
- When second hand components have not yet been found: use ranges instead of exact measurements in drawings when possible, to increase the chance of finding a product that fits.
- Consider the type of space when designing. How important are design details in that space? In for example a storage room or above a false ceiling, use of less beautiful, or miss-matching products, may suffice.

Interview with MATS ENANDER & AMANDA HÖJER

Mats - property developer at Vasakronan with an architecture background, mainly involved in early phases of projects.
Amanda - project leader at Vasakronan, with a civil engineering background.

Vasakronan have implemented circularity as a strategy in their properties and construction projects for several years. It is possible for them to achieve it in separate projects but they are aiming to explore it on a larger scale.

To do circular design

Mats and Amanda discuss how circularity can be implemented in different ways and in different scales. Components can be used again within the same project, or in another. They believe it is important to start the process with establishment of goals regarding the building and its purpose. These can guide towards making the right decisions and priorities - not all buildings and all spaces need to be "top notch" - it might be okay to have second hand, non-matching ceiling lights in a garage, for example. Workshops with different stakeholders can be a useful method during project planning to share knowledge and to find ways to go from the idea of circularity to realisation.

Gathering information

According to Amanda, the importance of product classification is often presented as more of an issue than it might need to be. For example regarding doors - in most cases, not that many doors in a building have to have a certain fire-resistance grade or sound insulation class, which emphasises the need for architects to more carefully consider the certain requirements of a specific space or design, when doing CD.

Challenges

A challenge for increased circularity within the building industry is, according to the interviewees, that there is no well-established structure or routine for doing inventories of existing buildings. To make this process easier, there is a need to establish what to include in the inventory, which parameters to measure, how to weigh these parameters and also how to record the gathered information in a manner that is clear and accessible. Another mentioned challenge is for architects to change their mindsets, from traditionally being able to design more freely, and have things more or less made to order, to instead base their design processes on already existing products. It requires a different approach.

Tips

- Look to circularity hierarchies for support in making design decisions.
- Be specific when considering a certain design choice. Ask yourself what is required from a certain design in a certain spot.
- Gather knowledge and experience of CD early in the design process, from other stakeholders involved in a project. Workshops can be a good method for this.

Interview with TANIA SANDE BEIRO

Sustainability consultant at White Arkitekter.

To do circular design

One difference between a conventional design process and the process of CD is that working hours when doing CD might have to be moved from early design process phases to later on. In a traditional design process, architects start with sketches that develop over time to become detailed drawings. Compared to designing with a circular use of components, there is more freedom in choices of design and material, and the final documents are much more detailed. When doing circular design, the architect may start with a conceptual idea of the design, but can not know exactly what the final design will look like until much later, when second hand components to use have been found. The design documents must be much less definitive, and can not prescribe specific materials, colours etc.

Gathering information

Information that is needed to use a second hand product is for example of which material it consists, how it is mounted, its measurements, placement and amount of products in the building. Parameters which can be evaluated and compared are for example lowered climate impact, circular potential, demountability, limitation of resources, amount, and economic value compared to new product. Tools to use to document the inventories can for example be excel, photos or the app Dacke by CCbuild. Different tools can be useful in different situations, and it is important to make sure to choose the appropriate tool. For example, to investigate the reuse of facades and facade elements, one might be looking for different information, as compared to if reusing furniture.

Challenges

Learning a new type of design process is time demanding. Architects' design processes are not tailored for CD - they are used to knowing what the final result will look like. Handling not knowing this, and still be able to communicate ideas to clients and stakeholders is a big challenge.

Tips

- If time is limited, prioritise to explore circular use of materials which can be found in large amounts, or that have a high potential for circularity.
- Design for demountability and disassembly.
- Agree on a circularity hierarchy for support in making design decisions.

Interview with THEA FOSS HENRIKSEN

Interior architect at Kanozi Arkitekter.
Involved in designing the "Arena project", a concept for shared office spaces using only second hand components and renewable materials, in Vasakronan's new building Platinan.

To do circular design

After identifying potential second hand components to use, more time is needed compared to in a conventional design process. This to have time to investigate how used components can be updated or fixed, also in relation to guarantees and certifications. Since it is preferred to use again without lowering the value or quality of a product, it is important to consider how each product can be treated with maintained, or even increased, performance. It is also important to have the potential for future cycles in mind when designing, and to avoid making decisions that will obstruct future circularity.

Gathering information

When choosing components made from up-cycled waste, it is necessary make sure that no excessive waste has been created just to create more resources for the components. To make sure that the most sustainable components are chosen, there is a need to also investigate the manufacturer, their process, and potential negative environmental impacts they might cause.

Challenges

A main challenge identified during the interview is the lack of established processes for CD. This includes knowledge regarding, and established contact with, different component suppliers and with companies to involve in restoring/developing components for circular use. Many of those connections are still not maid, which makes the process of a CD project much more time demanding, compared to more conventional design processes where contacts in many cases are already established.

Tips

- Look for innovative components and producers.
- Doing circular design, one can really gain from cooperating more closely with other stakeholders. Share knowledge and experience.

3B.

CASE STUDIES

Case study process

For case studies, ongoing building design projects in Gothenburg were chosen, which in one way or another address circular design, and which had gotten quite far in the design processes. This to be able to analyse a larger part of the process, and to be able to analyse consequences of choices made during the process to some extent.

Information has been gathered through interviews with involved architects, and in some cases also with representatives from the companies who own the buildings/ project clients. Documents such as pre-studies for the design projects have also been studied. During the case studies, focus has been on:

- How the architects have approached questions regarding circular use of building components.
- What methods and tools the architects have used.
- How, and what, information the architects have gathered to approach circular design.
- How above mentioned information has been used to make decisions in the design process.
- How goals regarding circularity have been established.
- How the architects have related to instructions regarding circularity from the project clients.
- What types of circularity that have been applied in the design.
- What elements of goal-oriented vs. means-oriented design that can be identified.

The three case studies have then been compared, based on above listed criteria. Applied types of circularity in each case study have been mapped using the circularity hierarchy by White Research Lab (2019, see figure 8a.) However, the different forms of circularity found in the case studies imply that more clarity in the analysis would be achieved if the top category (1. reuse of floor plan) in the hierarchy differentiated between reuse of floor plan and reuse of structure. Hence, category 1 of White Research Lab's hierarchy will from here on be divided into (1a.) reuse of floor plan, and (1b.) reuse of structure.

For each case study, a design process timeline has been produced, for the purpose of this thesis. The timelines are chronological and show, as described by the team of architects, important activities and main events during their process.

Learnings from the case studies have been used to build the means-inspired design process, contributing with methods and tools, and their insights and experiences have for example affected the order of activities in the MID process.

All questions that were asked during the case study interviews are listed in the appendix.

Case study of

EUROPAHUSET

About the building

Owned by Balder
White Arkitekter
Year of construction: 1988-95
Location: Västra Eklanda, Mölndal

Fig. 11. Photograph by Thomas Landenberg, reprinted with permission

The property consists of three large office buildings which are being turned into apartments. The buildings are quite new, so many parts are in good condition.

Process overview

In 2015, the property was for sale. Prior to a potential buy, White Arkitekter did a few sketches for the residential property manager company Balder, investigating different remodelling alternatives. The alternatives ranged from demolishing everything and building something new, to keeping as much as possible of the existing building. The choice was made to keep the structural framework, since it had both a high economic value and a large CO_2 footprint. Balder had not particularly pronounced an aim to focus on circularity in the project, and this decision was the first to be made with that concern. It sparked a discussion within the team of architects of what else could be used again. Since the building was fairly new, it was quite easy for the architects to see the potential value of several components, especially of surface layers.

Gathering information

A structured inventory with the purpose to investigate which components that could be used again has not been done, neither has the circular potential of different components been presented in any particular way. Information regarding interior and exterior materials has been gathered along the design process. One of the main questions has been to see whether it is possible, or not, to detach surface layers from their current uses. For example, there are textile carpets and stone tiles, which if they can be removed in entire pieces, easily can be reused in the new design. Some layers have shown to be impossible to remove without breaking, and for these, tests have been performed to see whether they can be mixed with virgin material and in that way be remanufactured. During the design work, quite a lot of time has been spent on such tests. For components which can not be neither reused as a whole nor as part of a new component, possibilities for energy recovery has been explored, to avoid landfill. It has been important to perform these tests before demolition starts, since the demolition process is so high-paced that there would be no time to separate and take care of components which have not yet been labeled for second hand use. Another, sometimes crucial, aspect to consider, has been whether the material can be stored or not, between its different uses. Except for the actual tests performed, the experience and knowledge of the architects have contributed in making decisions regarding the circularity. It has allowed for some conclusions to be made without collecting more specific information, such as that the circular potential for the hollow-core slabs is high and that there probably would be a relatively high demand for them, if they were to be sold.

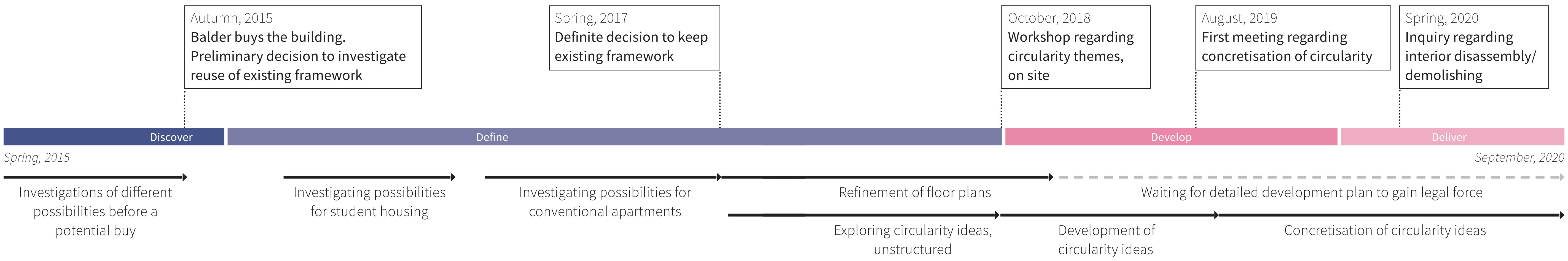
Effect on design process

The will to explore circularity has been fuelled by the interest of the architects, and the investigations done have been based on how the found components have inspired them. The architects have a list of components that might be possible to use again, which they explore. This has required a physical and experimental design process, working closely with the components. The architects have been to the building several times, to experience it on site and to learn all its spaces well. In some cases, the team of architects have reached out with specific questions to material specialists. One such question regarded crushing and reusing pieces of the pink facade elements in a mix with concrete to create terasso. It turned out to be impossible due to too much reinforcement in the facade elements.

Goal formulation

Even though not many goals regarding circularity have been formulated by the clients, there has been a shared will among the architects to work with CD. For example, even though it was decided to keep the structural framework, some of it still had to be removed, since the office building was to deep to hold apartments that fulfilled the daylight requirements. The architects' aim was to remove as little as possible of the structure, even though it would mean that they would have to spend

Design process timeline



a lot of time on floor plans, facade design och light reflecting materials to get enough daylight in the building. Regarding goal formulation for circular use of surface layers, the architects have had the approach that if a material turns out to be possible to use again, they will integrate it in the design. If not, then that is fine too, and no more effort will be put into investigations.

Challenges

Since the original measurements were set for an office building, it has been a challenge to design apartment floor plans that would fit, and to achieve enough daylight. Due to the different types of room sequences and movement patterns in office buildings, compared to in residentials, it has not been possible to argue for keeping more of the floor plans than structure and four stairwells. The change of the building's use has also made some of the products difficult to use again, such as glass partitions, which are common in office environments, but not as useful in apartment buildings.

MOD or GOD?

Both elements of GOD and MOD have been applied during this process, but on different scales. On the larger building scale, components which have turned out not to suit the design have been dismissed, in a more goal oriented manner. On the other hand, the way the potentials of different components have been explored has been more means-oriented, starting with the component to see how it can best be treated to become useful once again.

Circular strategies

The main focus has been circular use within the building, but other mentioned possibilities include to reuse components when building a few adjacent buildings, to reuse within Balder's building stock or to sell to others, who have shown interest, mainly in hollow-core slabs. The circular use within the building itself consists of:

Case study of KUSTGATAN 3

About the building

Owned by Familjebostäder
Sunnerö Arkitekter
Year of construction: 1968
Location: Majorna, Gothenburg

Fig. 12 Photograph by thesis author

The building has five stories in total, where the three top floors are residential and the two bottom floors have been used mainly for offices. The two bottom floors are now being turned into small apartments and spaces for co-living.

Process overview

A pre-study was done and presented during the spring of 2019, investigating two alternative ideas of how to use the space - either to maximize rentable area or to build smaller apartments but with more co-living spaces. The second alternative was chosen, and Sunnerö Architects were hired to continue the work with the new floor plans, which they presented in early February, 2020. Shortly afterwards, Familjebostäder, presented their decision to make Kustgatan their test arena where they would explore how to incorporate circularity in their building stock. As a first step, the company Reclaimd, was procured to do an inventory with the purpose of mapping products which had circular potential. The inventory was then shared with the architects.

Gathering information

Some information of importance was gathered already in the pre-study, before circularity was made a goal. It involved test sampling for asbestos (which was not found), measuring of radon level, which was below the allowed value, and a superficial examination of the building's general condition. The information was presented in a table, with short comments on condition or possible measures to be taken. In March 2020, the complementary inventory was done, mapping doors, windows, some glass partitions, lighting and fitments. During the inventory, there seem to has been a focus on products, rather than materials such as surface layers. The inventory was done using the app Dacke, by CCBuild, logging each product with placement in the building. Photos were also added to the product information in the app, and the products were rated based on different values, such as architectural value, possibility for disassembly, CO2 equivalent value, economical value and condition.

Effect on design process

Despite the fact that the circularity theme was not pronounced yet when the architects developed the floor plans, the new plans are based on some existing walls, which will be kept, for economic reasons. The material from the inventory was not made available to the architects until towards the very end of the design process, after floor plans and drawings had been finished, so there was very little time to explore how the material from the inventory could be combined with the proposed design.

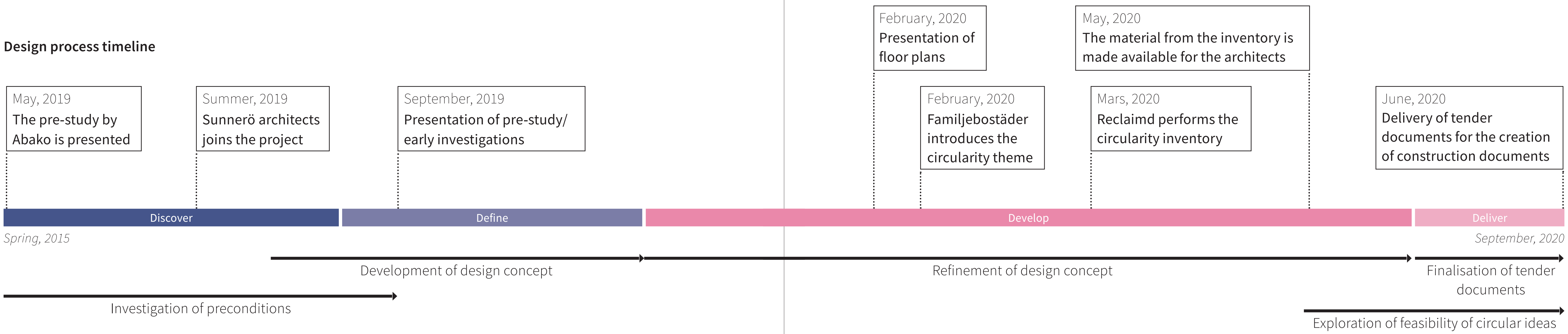
Challenges Due to technical problems with making the results from the inventory available to the architects, a greater challenge was created in succeeding to incorporate any of the inventoried components in the design before delivery. An additional challenge seem to has been that there has been varying ideas of the main purpose of the inventory within the project organisation. While the project group has discussed different ideas of how to apply circularity, both within the project and to sell for others to use, the inventory seems to have mainly covered types of products which can be sold for others to use. All in all, these challenges might have lead to quite a low level of reuse on the site.

Goal formulation The goal with introducing circularity at Kustgatan was to use it as a test bed for circular ideas within the organisation of Familjebostäder. Since the circularity theme was introduced late during the design process, different limitations have been discussed, and are still elaborated on, such as only working with circularity mainly in shared spaces. The lack of established, more clear goals regarding how to incorporate circularity might have resulted in a less efficient design process.

MOD or GOD? This has been a goal-oriented design process, finding components that match a developed design, rejecting those that do not fit (although, knowing that they will be sold and maybe reused by somebody else).

Circular strategies Reuse of floor plan and structure (established before the circularity theme was introduced), some reuse on site and some components will be sold to second-hand vendors. The circularity within the building itself consists of:

Design process timeline



Case study of

ARENAN + KROMET

About the building

Owned by Vasakronan
Kanozi Arkitekter
Year of construction: 2020 (Arenan)
and 1984 (Kromet)
Location: Gullbergsvass, Gothenburg

Platinan is a large office building, which will partially be constructed from parts from the next door building, Kromet, which is being demolished to create space for new development in the area. Arenan is shared office concept, a part of Platinan, and the main focus of this case study.

Process overview

Kanozi entered the project of Arenan, during the summer of 2019. They were given data from an inventory of Kromet, done by White Arkitekter. Instructions from Vasakronan, at the start of Kanozi Arkitekter's work, was to try to reuse the ceiling panels from Kromet in Arenan, with the additional instructions that if Kanozi Arkitekter found other components which might be used from Kromet, that would be encouraged. During the autumn, the design concept was developed side by side with component research. The architects held a concept presentation around Christmas, and presented the final design proposal in February. Since then, adjustments has been done. Investigations of other components to use from Kromet are still being done, such as seeing if large metal sheets from the facade can be used as interior sheet material.

Gathering information

The inventory White Arkitekter did was done in two steps. The first one on a more basic level, using excel, and the second inventory using the CCbuild app Dacke, where information and photos of individual components could be stored. However, a conclusion made from using the app was that it might be more useful during smaller remodelling projects, rather than a large-scale project like this, which is why excel in this case felt more practical, except for the lack of an easy way to include photos. During the design process, Kanozi Arkitekter have investigated both the ceiling panels and other components from Kromet. Information regarding possible circular alternatives has in many cases been gathered by contacting component suppliers and experts, rather than the architects performing actual tests themselves. The questions asked have often concerned possible methods of refinement, which could be applied without lowering performance or qualities. The process of investigating components from Kromet is still ongoing. Much effort during the component research has also been put into finding innovative materials - either made from upcycled waste or from renewable resources. When exploring these kinds of materials, the architects have been careful to understand the processes behind the materials, researching manufacturing, transport and types of resources. An important question researching materials made from upcycled waste, has been that the production itself should not encourage or produce excess waste just to create feedstock for the material production.

Goal formulation

The initial goals regarding circularity were quite openly written, and it has been up to the architects to define their interpretations. They have chosen to focus on upcycling and renewable materials, and their goal is that no other than such materials, complemented by some components from Kromet, should be used in Arenan.

Effect on design process

According to the architects, the fact that circularity was part of the project from the initiation, has led them to consider all component choices more carefully, to match the initial values set by Vasakronan. This has required a lot of time, to make sure that no hidden, negative climate impact come from the components chosen, and that the components have been responsibly produced.

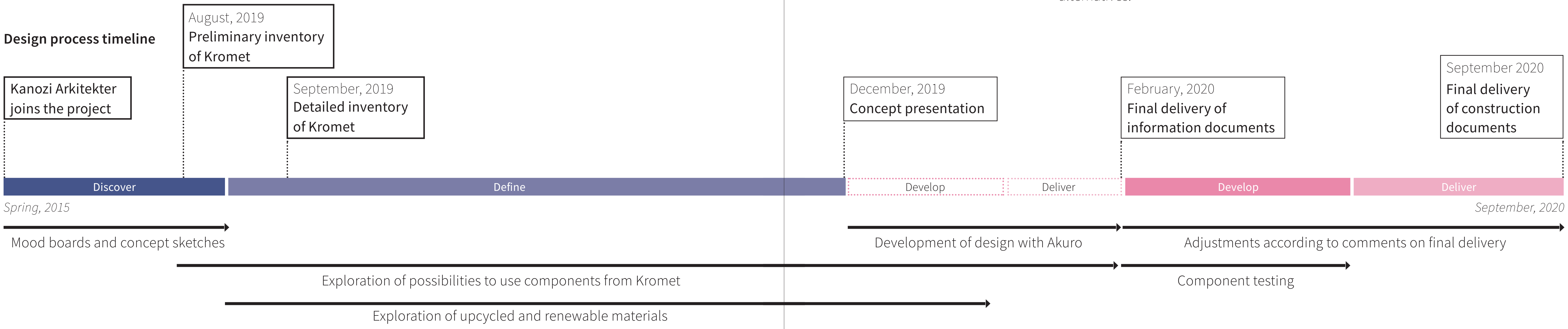
Challenges

It has demanded much time to find and establish contact with producers of new types of materials. Mapping them, making sure there are no hidden negative climate impacts have also taken a lot of time, much more than in a non-circular project.

The time between the concept presentation and the delivery of the final design proposal was short. It turned out to require close collaboration with Akuro, the hired project leaders, which according to the architects, in the end gave a better result.

The different time frames for Kromet and Arenan has made some components from Kromet difficult to reuse in Arenan, which has forced the investigation of other alternatives.

Design process timeline



MOD or GOD? The parts of the process connected to Kromet has been quite means-oriented, starting with identifying available materials and finding new uses for them. The parts connected to upcycling and renewable resources are, on the contrary, quite goal-oriented, where components have been searched for, to fulfill certain design.

Circular strategies Second hand use from and on other sites, through using parts from Kromet in other White projects, or by selling to other parties. A significant amount of upcycled materials and new materials made from renewable resources. The circularity within the building itself consists of:

REFLECTION

GOD or MOD During the interviews, elements of both goal-oriented, and means-oriented design processes, were discussed. To the persons interviewed, the chronology of the GOD design process appears to be almost unaltered when it is adapted CD. The main change, and challenge, is instead that, to make the GOD process useful, architects must learn new ways to design with less exactness. Architects must also develop adapted manners and tools to communicate that new way of designing. In the GOD process, the design is developed first, but in a way that allows for a spectra of alternatives for different components, which are then scouted, closer, or in connection to, the construction phase. Compared to traditional drawings and design documents, being less exact increases the odds for finding second hand products that fit, but it does create other challenges. For instance how to apply for a building permit, or to discuss the design, both within the team of architects, but also with clients and other stakeholders. It also requires that the architects are present during the construction process to a much larger extent, and that the communication between architects and the construction team works well. All parties involved in the construction must also understand the principles of CD, so that everything is assembled with methods that allow for disassembly, without relying on detailed drawings, since these might not always be possible to produce when designing with unknown factors. Yet another issue is that the current amount of products available for reuse is limited. This can result in several cases where the sourcing of fitting second hand products, despite allowing drawings, take long time, or even fail, leaving no other choice than to settle for newly-produced components.

If using a MOD process, it is possible that what will be used will be known earlier during the design process, and thereby offer a more controlled and methodical way to do CD. When a more MOD process is mentioned in interviews or case studies, it is mainly in connection to different remodelling projects, or where there are existing buildings being removed close to the site where a new building is planned. This does not have to be a precondition, but until a shared platform for mapping construction activities or available building components in an area is established, the prerequisites for a MOD process are more limited. The process is very dependent on timing - existing buildings must be disassembled to make components available at a point that correlates with the right construction phase of the a new building. This is not directly related to the design process but can have a direct impact on the possibilities for circularity. The increased amount of time needed in the project, to really investigate how used products can be treated, is a challenging aspect of MOD. The level of success of the project can also be partly dependent on the architects having physical access to the building, materials or products they are designing with, which can be problematic. However, a main challenge with MOD seems to be to move on from the inventory of components, to decide on a direction for the design, to establish a fairly efficient design process.

Neither of the purely means-oriented nor goal-oriented processes seem to be entirely supportive for architects in doing CD. To be able to develop a structure for a design process to follow for increased circular use of building components, one alternative could be to explore an intermediate alternative and to let the conventional, goal-oriented design process approach the means-oriented, in a process which could be described as means-inspired rather than means-oriented. The following chapter no. 4, will be devoted to such a process, a MID process, mapping its different potential components.

100% GOD → Means-inspired design ← 100% MOD

Other reflections for circular material use

- *The transition from one of the four phases - discover, define, develop and deliver, are seldom clear. Instead they overlap and can sometimes run parallel.*

- *Mainly focusing on circularity through upcycling and renewable materials does not seem to require a design process that is very different from the conventional one, except that more time can be needed to research components. However, this approach is to some extent based on the production of new components to get the circularity going. It focuses on the lower steps of the circularity hierarchies (fig. 8a and 8b) and does not address the whole challenge of CD, nor does it exploit all the potential for circularity that could be found in the existing built environment.*

- *The case studies use several types of circularity strategies to be able to increase the amount of circularity.*

- *The focus of the inventories done seem to differ in focus. In some cases, a focus has been on surface layers, in other, on fitments and smaller products. It appears to have, sometimes unintentional, consequences on what type of circularity that dominates the project.*

- *Even in projects that have a pronounced circularity focus it seems to be troublesome to find structures and working methods that assist systematically in doing circular design.*

- *Early establishment of clear goals regarding the circularity appears to be helpful in making design work more efficient.*

- *Through the interviews and the case studies, a lack of focus on future cycles can be identified. Design for disassembly is the only thing mentioned with connection to future cycles, and it is only mentioned during one interview.*

- *The theory that it is an advantage during a MOD process, to have components physically available for tests and examinations, seem to be confirmed by the case studies and interviews.*

- *There seem to be a disagreement regarding to what extent different product guarantees, certificates and classes actually pose an obstacle to increased circularity within the construction sector.*

- *During several of the interviews, it is pointed out that CD currently is very time-consuming, but that the establishment of structures both for circular design, and for construction, could make future work more efficient.*

- *Under the current circumstances, lacking well-established networks for dealing with second hand products, it appears to be helpful to have a larger organisation involved in the a construction project. It seems like a larger architecture office, or property manager company can partly work as a substitute for a marketplace, in order to distribute components between different projects.*

4.

MEANS-INSPIRED DESIGN

ABOUT THE PROCESS

This chapter will be devoted to the proposed structure of the means-inspired design (MID) process, which has been developed by the author of this thesis. The purpose is to provide architects working with circular design a proposed process, which can guide them through important steps and questions of their design work, which has its base in available building components.

Process sources

The MID process is based on the information collected from the literature review, case studies and interviews performed during the research for this thesis. Some references have been of greater importance for the creation of the process itself, such as:

- Interviews have contributed with unique insights into the actual, practical work of circular design, on a level that has not been possible to reach through only the literature references.
- Case studies, especially Europahuset. Despite not being initiated as a CD project they have developed their own routines with methods for hierarchic exploration.
- The initiative Cirkulära Göteborg, the circularity hierarchy by White Research LAB, and the 4R & 9R models. A important aspect of CD is to be able to weigh different alternatives against each other, and to make motivated priorities. Since there is a lack of established processes for CD, being able to rely on pronounced hierarchies can be helpful. These hierarchies have for example affected in what order different questions are asked in the suggested MID process.
- Literature which explore the concept of MOD and its components, such as "*Ways to study and research urban, architectural and technical design*" (de Jong & van der Voordt, 2002), "*Material (re)contextualization: goal establishment in means-oriented architectural design*" (Pereira et al., 2016), "*Superuse and upcycling through design: Approaches and tools*" (Altamura & Baiani, 2019), and "*Superuse: Constructing New Architecture by Shortcutting Material Flows*" (Jongert et al., 2007).

The relation to MOD/GOD

Neither means-oriented, nor goal-oriented design processes seem to fully support architects in doing circular design. MOD is not really compatible with the type of preconditions that are common in construction projects today, and GOD does not really seem to promote increased circularity. As we face the challenge to increase a circular use of building components, a design process which combines the ability to start in the available means, with that at the same time relate to the preconditions, could be an alternative. The aim of this thesis is to propose such a process, here called a means-inspired design process, since it is inspired by the ideas of means-oriented design, but without going all the way. Compared to the MOD-, the MID process aims to add more structure to the design process, and by asking the right questions, create a more efficient design process. Compared to a GOD-, the MID process departs from what components that are available. However, the MID process, as the GOD-, accepts that all second hand components which will be used might not be known until after the design phase traditionally would have been ended, and that design documents must be made to allow for these components to be scouted during construction.

Using the MID process

The MID process departs from the moment an architect is given an assignment, and assists in how to prioritise, what questions that could be to asked and what activities which could be done, in what order, and how the answers or results could be used. The expected final result if following the process is a design proposal involving as high a level of circularity as can be argued for in that certain assignment, including a plan for implementation which covers the questions that could be connected to the work of the architect.

The process is in this report displayed in a manner that can be perceived as linear, but if it would have been used in an actual case, the results from the different activities would have given a more iterative design process. A previous step is modeled to inform the next, but it is always possible to go back to repeat earlier activities to produce different, or more, results. In reality, actions would also continue past several of the steps, or might have to be moved to another step than where it is displayed in this version of the process, due to projects' specific external preconditions, such as storage and component availability, as can be seen in the case studies.

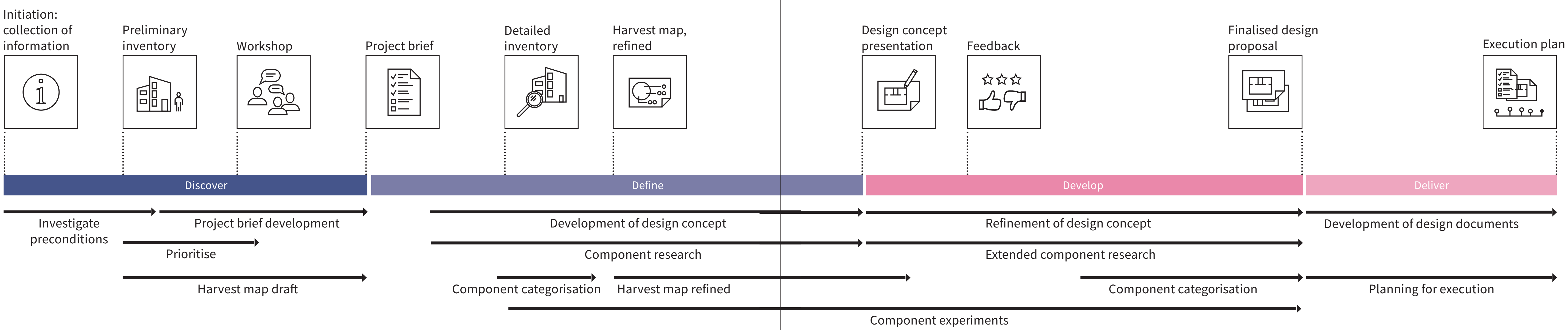
CD can take many different forms - reuse, recycling or upcycling, on one site or between different sites. The aim has therefore been to create a general process, to make it useful in different design projects when exploring which type(s) of circularity that suit their case. CD is not a copy-paste process, and the final result can be affected by many different criteria.

The idea is that the process shall be useful in design projects which vary in amount of circularity, both if it is 100% circular or if it is only partial. The MID process and its elements are also possible to adopt according to available time and resources. The idea is that it should be useful both in remodelling and renovations of different extent, and in new buildings, both if there is an available building to depart from on the site, or if building components must be scouted from other sources.

Additional comments

A common view is that CD takes a lot of time, which in several cases seem to be true. Therefore it is important that a schedule is set in the beginning of the design process, which decides approximately how much time that can be spent on each activity. Doing inventories and component research can be incredibly time-consuming, and must be given a certain amount of time to produce useful results. If working with limited resources (time or budget), it is important to have a clear prioritisation of what to focus on during inventories and component research.

What must be remembered as well, is that CD does not only require a new design process for architects, but also a new mindset, learning to see the potential for refinement in what is already used, and how the existing can become valuable sources of inspiration.



1. DISCOVER

Main focus

Investigating and defining project preconditions, creating an overview of the design task ahead.

Goals

The main goal during this first step of the process is to get a general understanding of the project's preconditions, by gathering basic information from influential parties. Such information should, for example, be time frame, budget, external circumstances, if there are any established goals regarding circularity, if there are existing buildings to start from, and in that case the condition of such buildings. These factors will together provide a direction for the continued work and an idea of how to approach the aspects of time, economy, quality and circularity in the specific project.

Tools

- Site visits, to start creating an image of the task ahead.
- Harvest map draft, to get an overview, and to start listing, means available.
- Workshop with main stakeholders, to discuss preconditions, early project results and potential continued directions.
- Sketches and fast drawings, to test if new functions can fit within existing floor plan or structure to see if it can be kept.
- Circularity and waste hierarchies, as support in choice of continued directions.

Results

A project brief, which shows:

- What basic preconditions for circularity there are.
  What is the time frame and the budget? Are there other relevant aspects to consider?
- What circularity strategies that seem applicable.
  Are there few or many second hand components which could possibly be used, or will there be a need to scout for other sources?
- What tasks that will be dominating the design work.
  Is the project to build something entirely new or are there existing buildings to adapt the design work to?

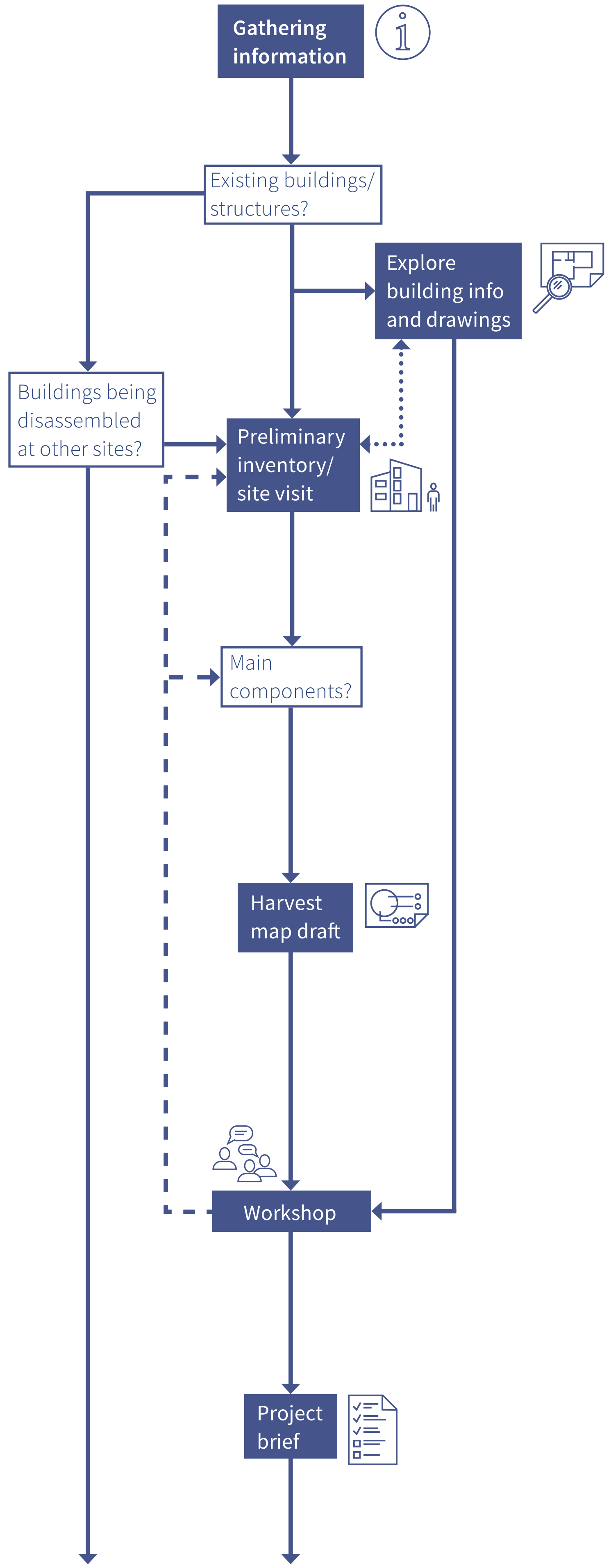
The purpose of the project brief is to get a shared view among architects and other stakeholders, of the basics of the specific project, to rely on during the design and the construction process.

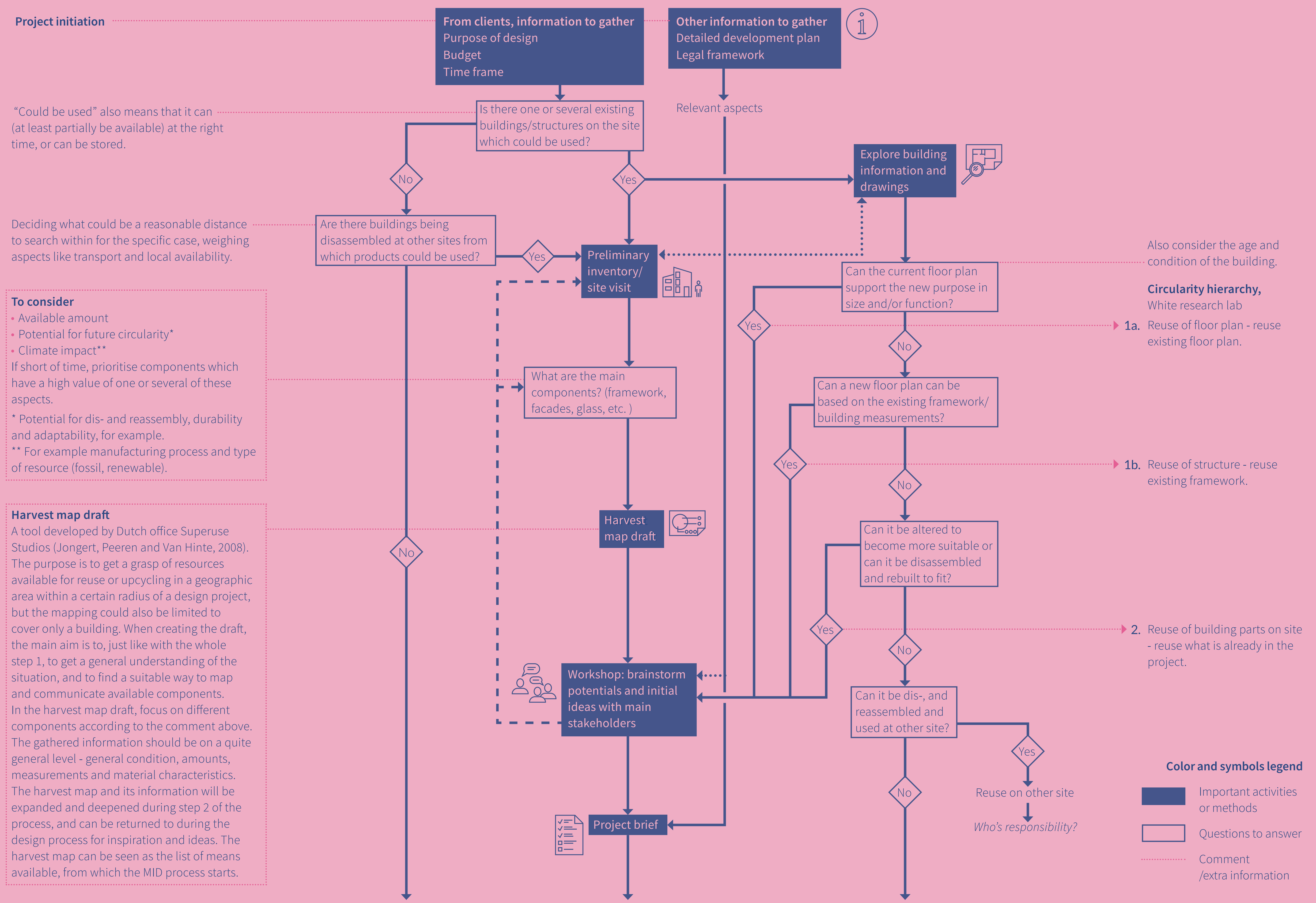
Comments

The goals set during step 1 are preliminary, and will be investigated further in coming steps of the process. The main purpose of setting the goals during this step is to provide a direction for the continued work, to support architects in investigating different possibilities for circularity in a structured manner, based on the potentials of a certain project.

The process of step 1 will look different, depending on whether there are available buildings to base the work on or not.

The extent of step 1 is very dependent on the amount of time given. More time and resources spent during this step allows for more investigations of more components, which will provide a strong base for the continued process. A thoroughly executed inventory takes time but facilitates the rest of the process, and is likely lead to a higher degree of circularity. Should there be less time, prioritise to explore components with a large climate impact, which can be found in large amounts, and/or has a known potential for circularity.





Project initiation
From clients, information to gather
Purpose of design
Budget
Time frame
Other information to gather
Detailed development plan
Legal framework
Relevant aspects
"Could be used" also means that it can (at least partially be available) at the right time, or can be stored.
Is there one or several existing buildings/structures on the site which could be used?
No
Yes
Explore building information and drawings
Deciding what could be a reasonable distance to search within for the specific case, weighing aspects like transport and local availability.
Are there buildings being disassembled at other sites from which products could be used?
Yes
Preliminary inventory/ site visit
Also consider the age and condition of the building.
Can the current floor plan support the new purpose in size and/or function?
Circularity hierarchy,
White research lab
Yes
1a. Reuse of floor plan - reuse existing floor plan.
No
To consider
• Available amount
• Potential for future circularity*
• Climate impact**
If short of time, prioritise components which have a high value of one or several of these aspects.
* Potential for dis- and reassembly, durability and adaptability, for example.
** For example manufacturing process and type of resource (fossil, renewable).
What are the main components? (framework, facades, glass, etc.)
Can a new floor plan can be based on the existing framework/ building measurements?
Yes
1b. Reuse of structure - reuse existing framework.
No
Harvest map draft
A tool developed by Dutch office Superuse Studios (Jongert, Peeren and Van Hinte, 2008). The purpose is to get a grasp of resources available for reuse or upcycling in a geographic area within a certain radius of a design project, but the mapping could also be limited to cover only a building. When creating the draft, the main aim is to, just like with the whole step 1, to get a general understanding of the situation, and to find a suitable way to map and communicate available components.
In the harvest map draft, focus on different components according to the comment above. The gathered information should be on a quite general level - general condition, amounts, measurements and material characteristics. The harvest map and its information will be expanded and deepened during step 2 of the process, and can be returned to during the design process for inspiration and ideas. The harvest map can be seen as the list of means available, from which the MID process starts.
Harvest map draft
No
Can it be altered to become more suitable or can it be disassembled and rebuilt to fit?
Yes
2. Reuse of building parts on site - reuse what is already in the project.
No
Workshop: brainstorm potentials and initial ideas with main stakeholders
Can it be dis-, and reassembled and used at other site?
Yes
Reuse on other site
Who's responsibility?
No
Project brief
Color and symbols legend
Important activities or methods
Questions to answer
Comment /extra information

2. DEFINE

Main focus

Expanding, processing and categorising components and component information according to potential for refinement, to produce a suggested design concept.

Goals

Continued component exploration, investigating more components and on a deeper level than the general mapping during step 1. During step 2, individual characteristics of different components should be taken in consideration, if there are variations between different components of the same sort. Such variations could for example be measurements or condition. This information will contribute to moving forward to more detailed design work.

Tools

- Refined harvest map - information gathered during several site visits where a detailed inventory is produced. Inviting other stakeholders to participate can give new perspectives. Based on the harvest map draft, but with new information added, to expand the list of available means.
- Component tests - can be of many forms, from physical experiments to workshops, sketching or modelling to see how the design concept can be developed. Reaching out to manufacturers can increase knowledge and inspire.
- Circularity and waste hierarchies, as support in choice of continued directions.

Results

A design concept, which shows:

- Basic ideas for circularity.
  What types of circularity could there be? How does it support future circularity?
- Possible handling of found second hand components which could be used.
  How could they be used again? What type of components have not been found, but will have to be scouted later during the process?
- Ideas for design concept.
  For example distribution of functions, flows, aesthetics.

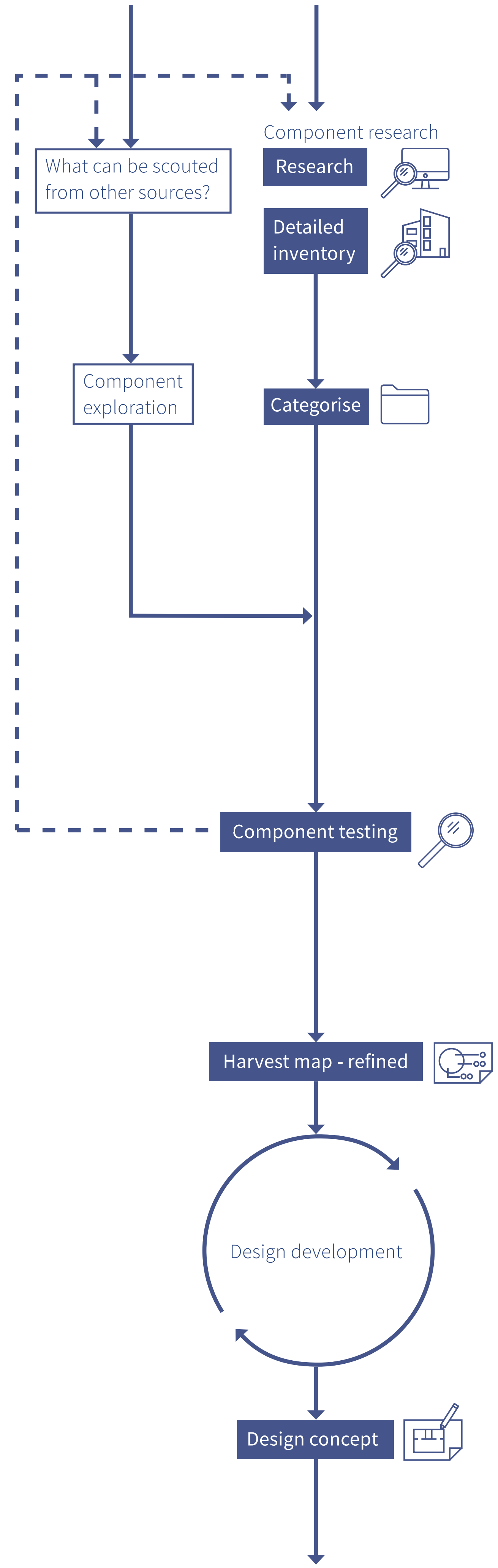
Comments

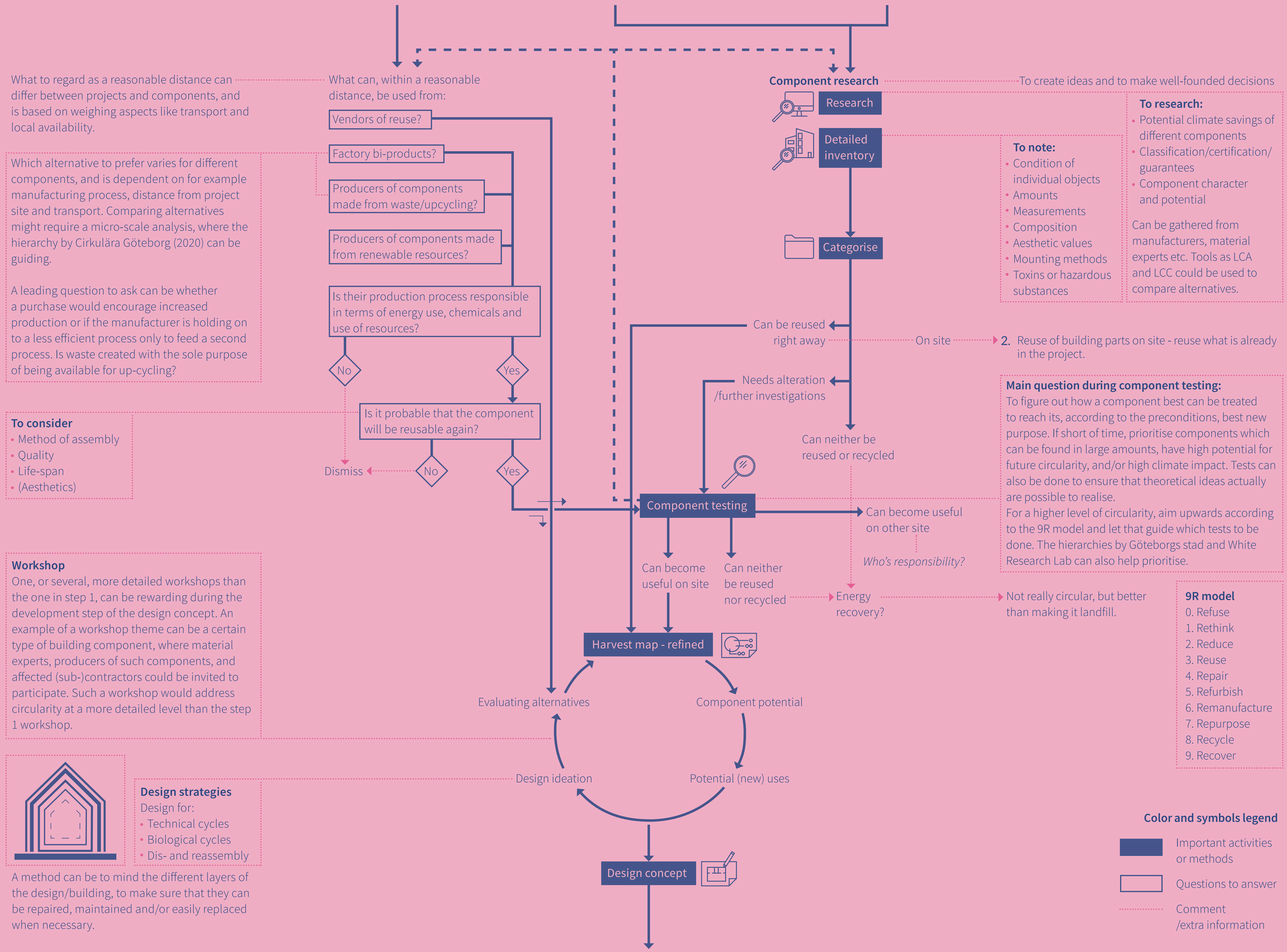
Just as for step 1, step 2 can be very time-consuming. A thoroughly executed inventory takes time but facilitates the rest of the process, and is likely lead to a higher degree of circularity. Should there be little time, prioritise to explore components with a large climate impact, which can be found in large amounts, and/or has a known potential for circularity. If there are no existing buildings to base the work on, much time can be spent researching other component sources. Setting an appropriate radius for the scouting can be a helpful delimitation. If component banks with circularity purposes would be further established in the future, that would save a lot of time during this step.

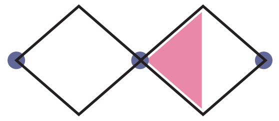
The categorisation of components is still rough in step 2, but will be refined later. The purpose at this stage is to give an overview of the circularity potentials.

During the component research, reaching out to experts or manufacturers can be of great help.

When contemplating circular use of a component on site, or whether to sell it to become somebody else's responsibility to give new use, remember that a circular construction sector requires not only a new design process but also a new mindset. On what basis are potential components dismissed from being used? Going back to the project brief can help as a reminder of the project's values.




What to regard as a reasonable distance can differ between projects and components, and is based on weighing aspects like transport and local availability.
Which alternative to prefer varies for different components, and is dependent on for example manufacturing process, distance from project site and transport. Comparing alternatives might require a micro-scale analysis, where the hierarchy by Cirkulära Göteborg (2020) can be guiding.
A leading question to ask can be whether a purchase would encourage increased production or if the manufacturer is holding on to a less efficient process only to feed a second process. Is waste created with the sole purpose of being available for up-cycling?
To consider
Method of assembly
Quality
Life-span
(Aesthetics)
Workshop
One, or several, more detailed workshops than the one in step 1, can be rewarding during the development step of the design concept. An example of a workshop theme can be a certain type of building component, where material experts, producers of such components, and affected (sub-)contractors could be invited to participate. Such a workshop would address circularity at a more detailed level than the step 1 workshop.
Design strategies
Design for:
Technical cycles
Biological cycles
Dis- and reassembly
A method can be to mind the different layers of the design/building, to make sure that they can be repaired, maintained and/or easily replaced when necessary.
What can, within a reasonable distance, be used from:
Vendors of reuse?
Factory bi-products?
Producers of components made from waste/upcycling?
Producers of components made from renewable resources?
Is their production process responsible in terms of energy use, chemicals and use of resources?
No
Yes
Is it probable that the component will be reusable again?
Dismiss
No
Yes
Component research
To create ideas and to make well-founded decisions
Research
Detailed inventory
To note:
Condition of individual objects
Amounts
Measurements
Composition
Aesthetic values
Mounting methods
Toxins or hazardous substances
To research:
Potential climate savings of different components
Classification/certification/ guarantees
Component character and potential
Can be gathered from manufacturers, material experts etc. Tools as LCA and LCC could be used to compare alternatives.
Categorise
Can be reused right away
On site
2. Reuse of building parts on site - reuse what is already in the project.
Needs alteration /further investigations
Can neither be reused or recycled
Main question during component testing:
To figure out how a component best can be treated to reach its, according to the preconditions, best new purpose. If short of time, prioritise components which can be found in large amounts, have high potential for future circularity, and/or high climate impact. Tests can also be done to ensure that theoretical ideas actually are possible to realise.
For a higher level of circularity, aim upwards according to the 9R model and let that guide which tests to be done. The hierarchies by Göteborgs stad and White Research Lab can also help prioritise.
Component testing
Can become useful on other site
Who's responsibility?
Can become useful on site
Can neither be reused nor recycled
Energy recovery?
Not really circular, but better than making it landfill.
9R model
0. Refuse
1. Rethink
2. Reduce
3. Reuse
4. Repair
5. Refurbish
6. Remanufacture
7. Repurpose
8. Recycle
9. Recover
Harvest map - refined
Evaluating alternatives
Component potential
Design ideation
Potential (new) uses
Design concept
Color and symbols legend
Important activities or methods
Questions to answer
Comment /extra information



3. DEVELOP

Main focus

Developing and refining circular ideas together with the design concept.

Goals

Concretisation of the component research, investigating components on a deeper level than during step 2, and if necessary adding research of, for the process, unexplored components. Development of ideas of how the components could be paired with circularity strategies and what measures that would require, established through a systematic gathering of more concrete information regarding the components' different aspects. An understanding of which measure that could be relevant for each component, based on weighing the factors of money, time, quality, potential climate savings and general feasibility. Development of the design according to the results.

Tools

- Component investigations - sketching, modelling, physical material experiments, mapping different kinds of relevant information. Evaluating findings from different perspectives, such as economy, feasibility, future circular potentials created and how components best can develop the design concept.
- LCC/LCA or simplified versions, to use in component comparisons.
- Circular design strategies for closing loops.
- Circularity and waste hierarchies, as support in choice of continued directions.

Results

Answers to the questions:

- What components will be reused?
  Where can they be found, in what way can come to use again and what measures would that require?
- Is there a remaining need for any kind of supplementary components?
  How can that be dealt with in the design? What requirements can be stated?
- How does the design enable future circularity?
  Assembly methods, choice of materials, surface treatment etc.

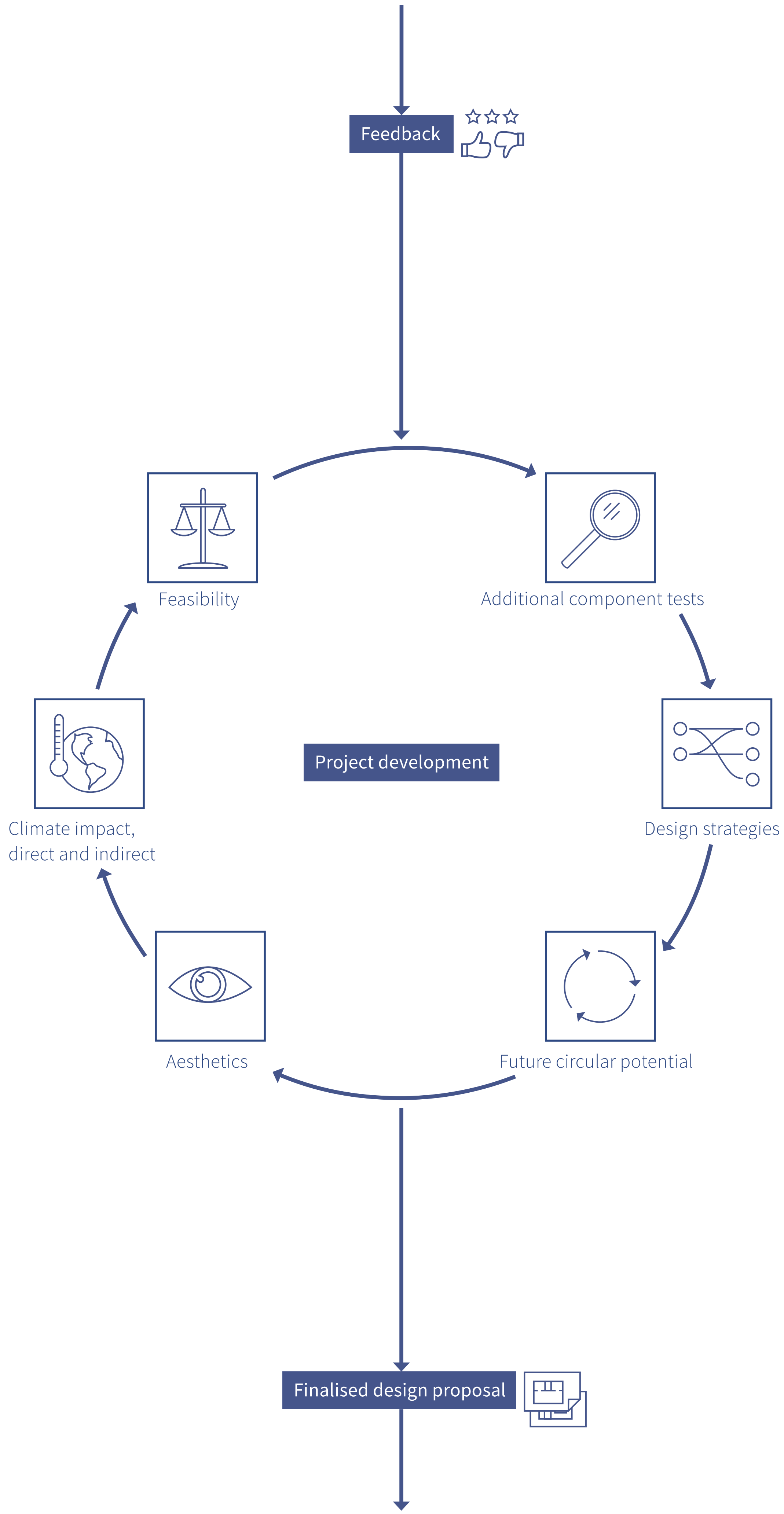
Comments

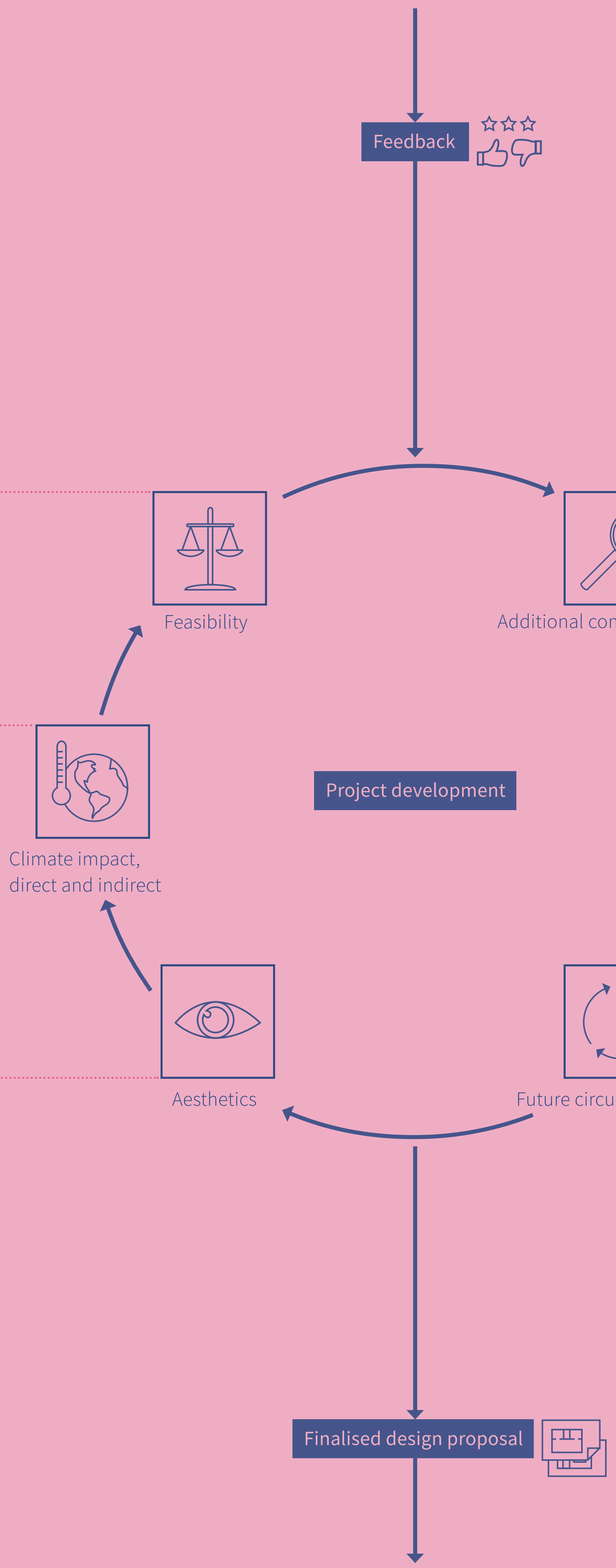
Also this step can take much time, if allowed to. More time available during step 3 increases the possible number of components which can be investigated, or to which depth they can be explored. If having less time available, prioritise as in step 1 and 2 (amount, climate impact and future possibilities for circularity).

Even after step 3, not all components the design will consist of, are likely to be known. Some of these will probably not be found, or, secured, until the demounting- or construction phase.

Testing of found components will probably occur parallel to the scouting of supplementary components.

During the process, it is important to remember that the aim is not only to enable circularity this one time, but also to simplify future circularity. Design choices should be made with that in mind, by for example using appropriate "closing the loop" or circularity strategies.





Feasibility
To make sure that proposed ideas are feasible in terms of economy, time and logistics, by weighing cost, time required, quality and circularity to find. How the different aspects are prioritised is often project specific.

Climate impact
To compare the total environmental impact from different alternatives. For an all-covering picture, lots of information regarding the component is needed, such as its sourcing, manufacturing process, and transport needs. LCA calculations can be made, or standard values used for a simplified version. Either way, it is important that different options are compared within the same framework.

Aesthetics
Testing different options for how the component best can be refined to its (new) use. Also how different components together can create an aesthetically pleasing, functioning, quality design.
Tools: sketching, modelling, etc.

9R model
0. Refuse
1. Rethink
2. Reduce
3. Reuse
4. Repair
5. Refurbish
6. Remanufacture
7. Repurpose
8. Recycle
9. Recover

Additional component tests
Continued exploration of options for different components or designs. For a higher level of circularity, aim upwards according to the 9R model and let that guide which tests to be done. The hierarchies by Göteborgs stad and White Research Lab can also help prioritise.

Design strategies
To find the most suitable design strategies, which allow components to be used again with preserved value, or increased value.

Design for:
- Technical cycles
- Biological cycles
- Dis- and reassembly

Future circular potential
To make sure that the design does not discourage future circularity, by adapting the design to the different lengths of life-spans, and also considering standardisation, quality, durability and flexibility.

Color and symbols legend
Important activities or methods
Questions to answer
Comment /extra information

4. DELIVER

Main focus

Producing and presenting material which communicate the project and its ideas.

Goals

During the last step, the main activity is to finalise the project and to produce all material needed for documentation and presentation. The material should be modelled in ways that support the communication of both decisions that are already made regarding the design, and matters that have to be figured out later during the construction process. Since there might be a lot to be communicated regarding circular building design projects, finding efficient tools for the purpose might be a challenge. In addition to producing the communication material, certain agreements might also have to be figured out during step 4, such as economic and juridical responsibilities connected to the future circularity of different components.

Tools

Can differ from one project to another, but could for example be:
- Drawings.
- 3D-models.
- BIM for material IDs and other information.
- Contracts to divide responsibilities.
- Documents stating how the circularity is to be realised.
- Other, for the project relevant, tools.

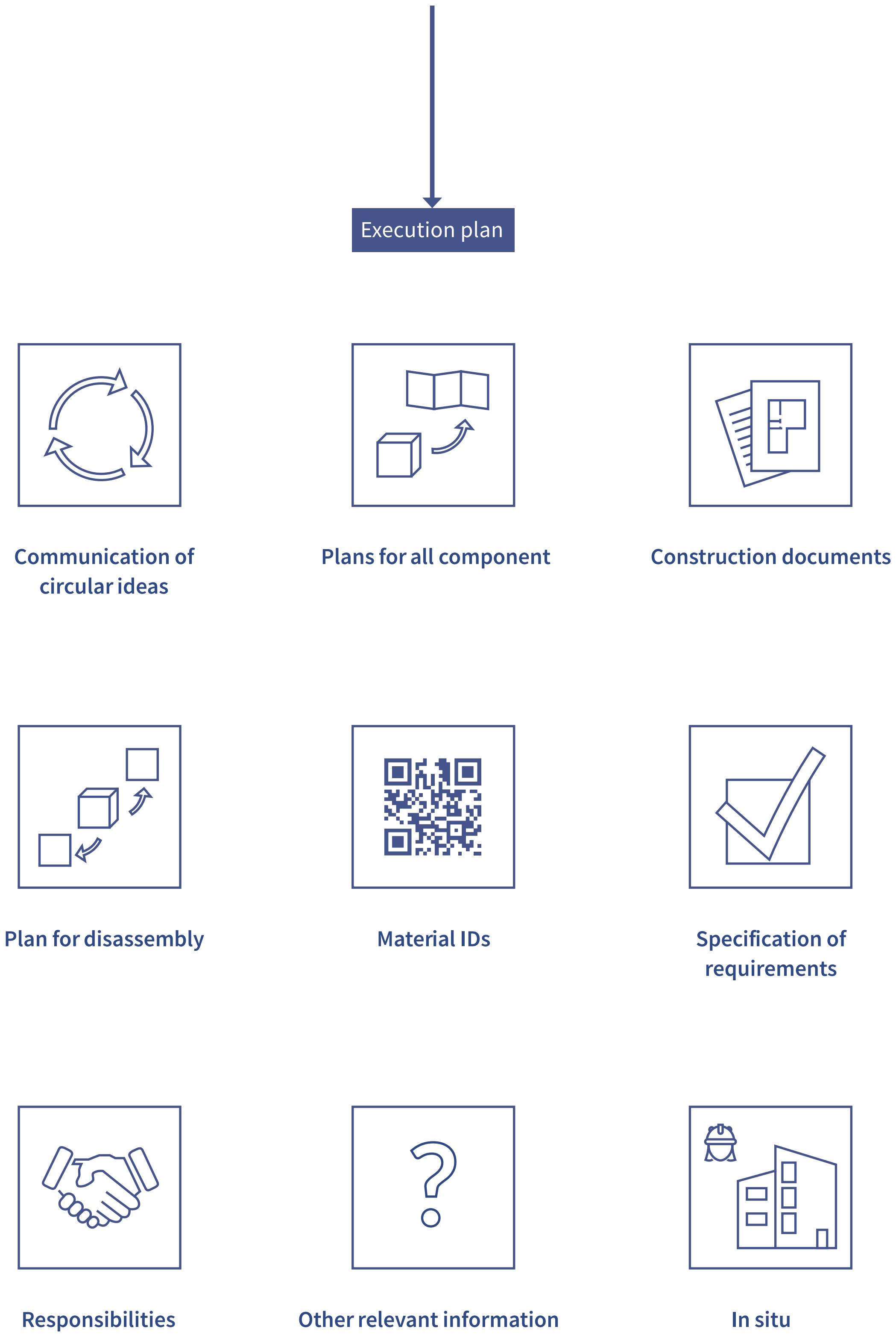
Results

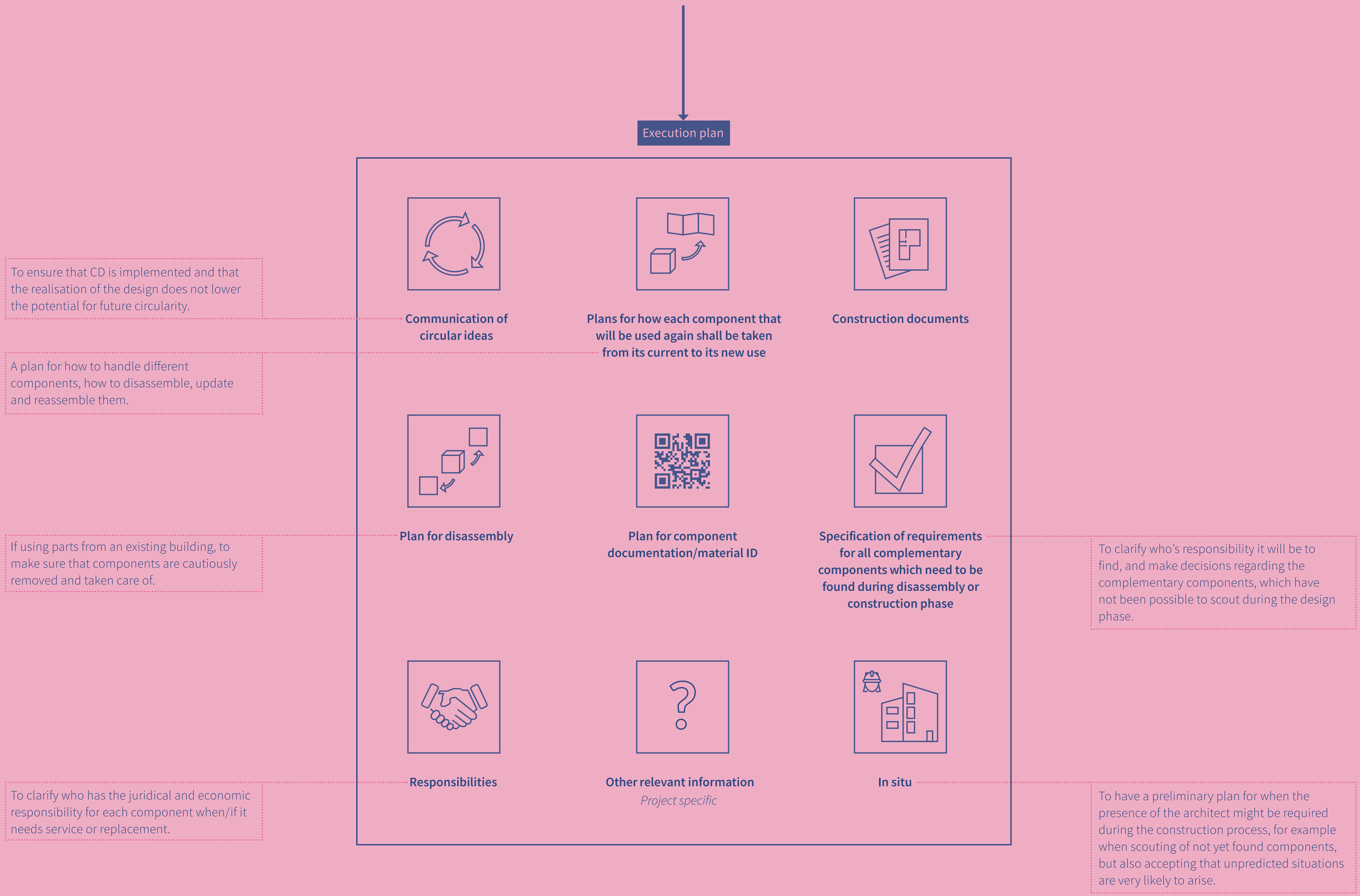
Communication material which explains:
- The design.
  Construction documents and illustrations, which, for known components, need to make sure that assembly methods allow for future circularity, and for unknown components, need to be allowing enough so that fitting components later can be found.
- The circular ideas of the project and how they are to be implemented.
  Explaining how each already used component is to be handled and given its new purpose, component and construction assembly methods, how to handle material IDs.
- Juridical and economical agreements.
  Might not be the architect's responsibility, but the architects could contribute to the discussion, since the architect has insights into potential futures of different components.

Comments

The more carefully the documentation has been done during steps 1-3, the less time step 4 will require.

The communication regarding components, which have to be searched for during the construction process, should be more allowing than traditional design documents, to increase the chance of finding components that fit. That could, for example, be achieved by focusing on function rather than certain aesthetics, or by using ranges for measurements. Aspects to consider when deciding on how specific a requirement specification could be allowed to be, is how common the component is on the second hand market, how much time or economic resources there are, or how many of the component that are needed.

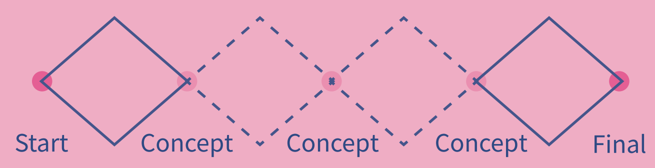




Execution plan
To ensure that CD is implemented and that the realisation of the design does not lower the potential for future circularity.
Communication of circular ideas
Plans for how each component that will be used again shall be taken from its current to its new use
Construction documents
A plan for how to handle different components, how to disassemble, update and reassemble them.
If using parts from an existing building, to make sure that components are cautiously removed and taken care of.
Plan for disassembly
Plan for component documentation/material ID
Specification of requirements for all complementary components which need to be found during disassembly or construction phase
To clarify who's responsibility it will be to find, and make decisions regarding the complementary components, which have not been possible to scout during the design phase.
Responsibilities
Other relevant information
Project specific
In situ
To clarify who has the juridical and economic responsibility for each component when/if it needs service or replacement.
To have a preliminary plan for when the presence of the architect might be required during the construction process, for example when scouting of not yet found components, but also accepting that unpredicted situations are very likely to arise.

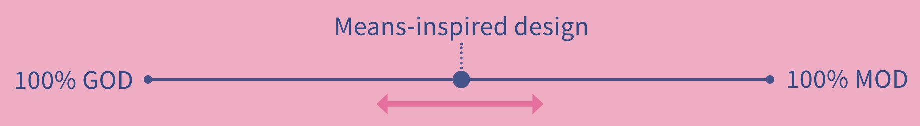
REFLECTION

Just as a majority of conventional design processes, the MID process is an iterative process. During the process it is likely that there will be loops back to previous activities, if for example having a setback, reaching a dead end, or if unexpected discoveries are made. It is also probable that several concepts will be produced during the process and just not one, in such way that the cycle of collecting and screening information will be repeated several times.

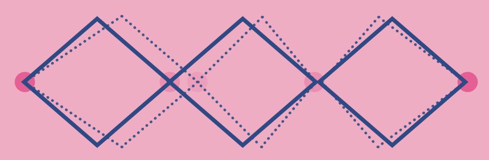


The four steps, and the activities within the steps, will require different amount of time. Activities which probably will need more time is for example the detailed inventory and the component research. With more experience and earlier knowledge, they can become slightly less time-demanding. Steps that could take less time, but still could contribute strongly to the process, are the workshops, if they are well prepared.

Depending on a certain project's values, the MID process can move in either direction on the scale between GOD and MOD. For instance, the more different places components need to be scouted from, the more close to GOD the MID process might have to be. This would require, instead of experimenting with component potentials, more focus to be put on creating allowing design documents. The MID process proposal might be a little less supportive during such a design process.



Some of the activities might stretch across several of the four steps, as for example the component research has done in the case studies of Arenan and Europahuset. Different tracks within the same project can also address different steps at the same point of time, as in the case study Arenan where investigations of up-cycled materials have been finished, while the experimenting with components to use from Kromet in Arenan still are performed. This might blur the transition from one step to another, but keeping in mind in which part of the process one currently are, can help to stay focused and to remember the purpose behind one's work.

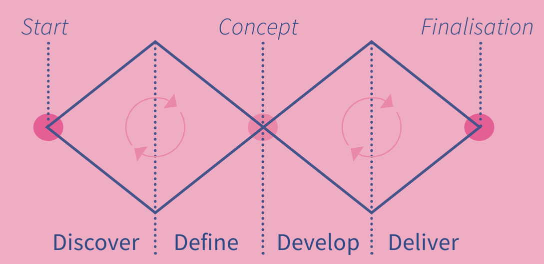


SUMMARY OF CHAPTER

Means-inspired design

Based on findings from literature, case studies and interviews, this thesis proposes a process structure for a means-inspired design (MID) process. The aim has been to develop a design process which is hybrid between means- and goal-oriented design. As in MOD, the MID process departs from available means, but simultaneously accounts for the project's other preconditions, as a GOD process. The aim is that the process could be used by architects designing for a circular use of building components, by guiding them through the different steps of the CD process, suggesting what information to gather and when. It also suggests how to make decisions based on the information collected, to help make advancements in the design process. It is supposed to be applicable to projects with different amounts, and types of, circularity, and adjustable according to the size of budget or amount of time available.

The process is divided into four main steps, where each step is informed by the results by previous steps:



1. Discover

To investigate and define project preconditions, to create an overview of the design task ahead. Main activities and tools are to collect information regarding the preconditions, site visits, a preliminary inventory of available means, and to create a map of identified components in a harvest map draft. If there is an existing building to start from, sketching is initiated, to explore to what degree existing structures could be kept. The result of the first step is a project brief.

2. Define

To expand and process component information and to categorise components according to potential for refinement, to produce a suggested design concept. Main activities are component exploration through component testing and research and scouting of other potential sources of second hand components. This information is added to a refined version of the harvest map. From the component information collected, a design concept is developed and presented at the end of this step.

3. Develop

To develop and refine circular ideas together with the design concept. Main activities are continued component explorations and tests along with refinement of the design concept, matching found components with appropriate circular design strategies.

4. Deliver

To produce and present the material which communicate the project and its ideas. Main tools are for example drawings, models, BIM, and different types of documents and other methods for communicating the design and its details.

5.

DISCUSSION

DISCUSSION

The topic

Finding literature references which treat circular building design specifically, and not just circular design in general, has been difficult. At the same time, it is a topic which is currently discussed intensely within the construction sector, but of which not much result has been seen yet, in the form of completed circular construction projects. Some of the literature studied claim that CD requires a new type of design process, a means-oriented process, which is based on what available materials there are. The same literature also claim that MOD processes often become inefficient due to lack of established structure, and that an entirely MOD process rarely is applicable. This seemed to be confirmed by the interviewees and case studies. Whether a more means-oriented design process is needed to be able to do circular design has not yet been proven, but it seems like a process which approaches means-oriented design, could give a more controlled circular design process and design result, than if using a conventional goal-oriented design process. This thesis therefore proposes a design process which is inspired by MOD, a so called means-inspired design process (MID). The MID process departs from available means, but in parallel work with ensuring that external requirements are developed and fulfilled, with the aim to support architects working with CD.

The tool

Interviews and case studies done during this master thesis has confirmed that for many of the architects who do CD, the process demands much time and resources, simply to understand the new task and how to accomplish it. There is a lot of information to collect and evaluate. If using the MID process as a structural guide, it could provide short-cuts, saving time and efforts when not having to figure out how to approach each step of the design process or what questions to ask. Displaying some of the basic information needed for circular building design, it could allow architects to make faster advancements in the design process, while still making informed, well-informed decisions.

A digital tool

To really become user-friendly, the MID process could benefit from being translated into a digital format. That would allow for more convenient integration of information, where the user could choose what information to show, and to what extent, based on the specific project, or on her/his own earlier experience or knowledge. It could also support the user returning during several, spread occasions, which could be necessary since the process that the MID process aims to cover could continue for several months, or even longer. Case studies and interviews indicate that it is likely that different tracks of a design project will be in different stages (step 1 - 4), at the same occasion, in which case a digital format could make it easy to return to the desired part of the process, and move on to the next part of the process once finished. There could also be several view modes, adapted to different kinds of occasions, for example one which offers a process overview with only main components, and another mode which is more rich with information. In that manner, much more of the information which could be useful during a CD process could be added, without creating visual chaos. For a paper version of the process and its steps, this would be much more challenging, which is why the information added to the process in this booklet has been kept slightly shorter. A possible disadvantage of not having it physically present, could be that it is forgotten about once the design process has gotten further and other questions start to distract. A possible solution could be to offer a printable version of the digital process, which could be added to a physical mood board or workspace.

Handling information

With this said, the MID process structure proposed by this thesis does not contain all information that architects need in order to do circular design. Architects using it would also have to search for additional information themselves. Considering how many building materials and products there are, it would not be possible to include information about all of them in the process line. Neither has that been the aim, since the strength is to guide users in what information to look for, and when, which can be challenging enough in CD. A potential development of the process could be if it to a greater extent, could support users in how the information that is collected about different components, as part of the process, can be weighed and compared. On the other hand, such comparisons can be very case specific and difficult to give general answers to.

The circular design process

A matter that has become clear during the development of this master thesis and through the proposal of the means-inspired design process, is that circular building design involves many areas of expertise, where some are beyond the traditional responsibilities of architects. The interviews and case studies which have been carried out show that this can be handled differently, in different design projects. Some have started to collaborate much more with other stakeholders and professions, to share knowledge. Others have aimed towards finding the solutions in-house, by employing experts or educating staff members. What is the best functioning solution seems to differ between projects, and the question remains regarding how to add these new skills to the construction sector. It is difficult to give a general answer to whether it should it be assigned to architects to extend their scope to become experts at all aspects of circular building design, or if a better solution would be for architects to learn the basics, while a new role is established to shoulder the expert role. Regardless, the different professions within the building industry must learn to collaborate more extensively, if we are to succeed in adopting such an intricate system as circular economy. This could possibly be achieved through basic understanding of each others' areas by sharing more knowledge, and through more transparency within construction projects as we work toward common goals. Another part of the solution could be to, through regulations, make sure that information which is needed to do circular analysis of building components, is made easily available, which is not always the case today.

New tasks

The new areas of knowledge, added to the design process, also bring new tasks. It is in many cases yet uncertain which profession who should perform these. They have, however, been included in the MID process proposal since they can be of great importance for the direction of a design process. With that said, it does not necessarily have to be the architect who accomplishes the task, but it could be the architect who makes sure that the result of the task is appropriately considered during the design process. Who will actually perform the task itself, is likely to differ, depending on the extent and preconditions of each project.

The research process

During the literature review, some of the texts which were studied concerned design in general and not building design specifically. Despite being careful when translating the findings regarding general design processes to building design, some conclusions have had to be made, which could have been slightly more dependable if all the literature would have concerned building design.

The number of case studies and interviews done has been limited, and located within quite a small geographic area. It is possible that variations within the results would have occurred if more data would have been collected, from a more wide-spread area, since some of the data sources which were used, have contributed with some inspiration to other used sources.

The case studies have differed in size, use, type of construction project (remodelling, renovation or new building), and to what extent the involved parties have had earlier experience from circular building. Even though that has made some comparisons more complicated, it has also indicated that there are some general patterns which are similar regarding CD, to be found among the case studies. Based on this, some conclusions of CD have been possible to make despite the variations of types of case studies, which have been essential to the development of the MID process, such as the importance of the physical component testing and the inventories.

This thesis's focus has been on circular use (reuse, recycling, etc.) of building components and has not covered the other two aspects of circular design: prolonged life-spans and increased utilisation. Future research could be aimed towards these two aspects, to investigate how they through activities or questions could be integrated in the MID process tool.

Topics for future research

There are several issues connected to CD, which have not been explored in this thesis but which need further investigation, and for which, leading questions or actions could be further integrated in the proposed MID process. One example is the relationship between the MID process and what type of contract that is used within a building project. A general comment from the research reviewed during this thesis, regarding type of contract and CD, is that CD demands a contract which enables collaboration between different stakeholders involved. This is applicable for the MID process as well. Another theme which would need more research is the connection between the MID process and deliverables at different stages of a design process.

There are also themes, which are not directly within the traditional responsibilities of architects, where new structures need to be developed. Several of these themes are mentioned in the beginning of this report, such as legislation, circular economic models, solutions for storage of components between uses and methods for sharing and keeping material information. All these aspects can have great impact on the potential for circularity, but are difficult to answer in general and often need to be solved project specifically. To be able to weigh different design options against each other, there must also be more of an agreement of how to measure circularity. What aspects are most important to consider when measuring circularity and how can different alternatives be compared? To be able to make the most sustainable decisions, more research within all mentioned aspects are needed.

CONCLUSION

Summary

The purpose of this thesis has been to increase knowledge on circular economy and how its principles can be adopted by the construction sector to reach a more sustainable use of natural resources. The aim has been to propose a structure for a design process which supports architects in designing for a circular use of building components. Since a majority of the literature which can be found on circular design concern design in general and not building design specifically, a larger literature review was done to be able to translate the findings to the construction sector. The literature review was complemented with interviews with architects working with circular design and with case studies of three different, ongoing construction projects which are implementing circular design, to collect information regarding circular design in practice. Based on the research results, a means-inspired design process was developed for architects to follow during circular design processes. Starting from available means, the MID process guides architects in what methods to use to gather which information, and at what time during the design process. It also suggests how to make decisions based on the results from the different methods.

Research questions

How can architects change their design process to design for a circular use of building components, in order to create circularity in the built environment?

By learning that to a further extent base design on what means that are available, and to see how values of used products can be retained, or even reinforced. By making available means the core of the design process, as an involved aspect of the design process already from its initiation, used components can through careful treatment be given new purposes, and so hence be kept in the loop, contributing to circularity in the built environment.

Sub question 1

What is circular economy and circular building design?

Circular economy is a system which aims towards eliminating waste by closing resource loops, through smarter design and through changing human consumption behavior, from a linear use of resources to a circular use. To do circular building design is to design for circular economy, by designing buildings which are made from an optimal use of materials, that are functional and that deliver the best performance, with minimised negative environmental impacts all along their life-spans.

Sub question 2

What challenges is the construction sector facing in adapting circular economy principles?

Working with circular economy and circular building design requires expanded knowledge on several topics. The challenges are many, and of varying themes. They range from lack of knowledge and experience, to legislation and industry standards to established economic systems.

Sub question 3

How can a design process be structured to support architects in designing for a circular use of building components?

It can be structured to guide architects through the different steps of the circular design process, by explaining how, and when, to explore, investigate and analyse the components that are available, and the preconditions that exist, in a specific project. By offering guiding in what information to evaluate regarding different components, based on established circular hierarchies, guide in how to make systematic, well-founded decisions, it can support architects in developing circular design proposals, supported with relevant arguments.

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IMAGES

Images with no reference have been developed by the author of this thesis.

Figure 1. European Commission (2008). 4R model. Retreived from http://ec.europa.eu/environment/

Figure 2. Potting, Hekkert, Worrell and Hanemaaijer (2017). 9R model.

Figure 4. Göteborgs stad (2019). Potential for material recycling for different phases of the construction process.
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Figure 5. Göteborgs stad (2020). Ten prerequisites for a circular built environment.
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Figure 6. Ellen MacArthur Foundation (2015). Biological and techncial cycles.
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Figure 7. Brand (1994). How buildings learn: What happens after they're built.

Figure 8a. White Research Lab (2019). Circularity hierarchy. Retreived from http://ccbuild.se/

Figure 8b. Göteborgs stad (2020). Circularity hierarchy. Retreived from http://goteborg.se/

Figure 9. Pereira, Datta and Mancini (2016). Comparison of MOD and GOD processes.

Figure 11. Landenberg (2016). Photograph of Europahuset. Reprinted with permission.

APPENDIX

Questions asked
interviews

- What challenges do you see in the construction sector adopting the principles of circular economy?
- What do you believe is the architects' responsibilities in a transition to CE?
- What can architects do to support a transition to CE?
- Do you think that the role of architects differ in a conventional design project, compared to in a project which applies CE principles?
- Do your work process differ when doing circular design, as compared to when doing conventional design? If yes, what are the differences?
- How do you find information regarding CE and CD? Where? Have you encountered any challenges in finding information?
- Do you perceive that there is support from research in how CE can be implemented in the construction sector, and/or in the practice of architects?
- What have you learned about circular design so far?

Questions asked
case studies

- Tell me a bit about the project: what has been the preconditions and where did you start?
- In what ways have you incorporated circularity in this project?
- Was the question of circularity part of the project from the start? If yes, how was it defined?
- Did you establish goals regarding the circularity during the design process? If yes, what goals and how were they established?
- Describe your design process. What elements has there been? Have you experienced some elements/activities as more important than others for the circularity of this project?
- How has components which could potentially been used again been identified and analysed? What kind of information has been collected?
- How has the information been used during the design process after being collected?
- Has the circularity focus lead to a design process that differs from how you usually work? If yes, how?
- How have decisions regarding the circular aspects of the design been made? What have they been based on?
- Do you think that you have enough knowledge regarding circular design and circular economy when you entered this project? If not, how much effort has been required to find information, and where have you searched?
- What challenges have you experienced with designing this project?