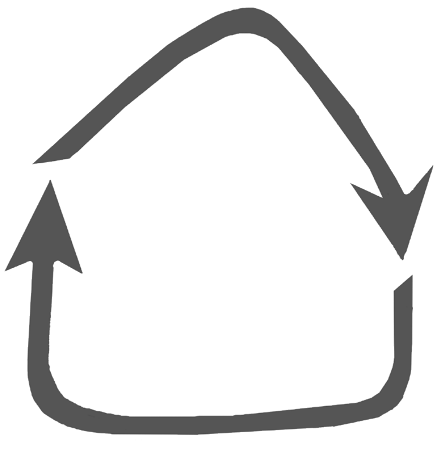
HOME AGAIN

How to facilitate circularity in the production process of social housing



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Home Again: How to facilitate circularity in the production process of social housing

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PREFACE

We live in a world with limited resources and our population is growing every day immensely. I started this research with two great challenges of the 21st century namely, social housing shortage and raw materials scarcity. The global process of unlimited population growth, marked by rapid urbanization and fast growing consuming economies, will lead to an immensely demand for resources in the next few decades. The building industry has a big impact on these problems. With the current linear process where we take, use and dispose we will not survive. We need to change into a circular process where there is minimal waste and where we focus on the reuse by keeping the value of our goods.

This research looks into the production process of the contruction company Think Wonen to improve some of the aspects to facilitate the transition towards a circular process. Small changes can make a big difference. The design of a few changes in some of the components of a house enhances the possibilities for future reuse.

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ABSTRACT

The need for social houses in the Netherlands has grown with the arrival of the asylum seekers. Today there is an estimate of around 150.000 housing shortage in the Netherlands. And the expectation is that in 2020 this number will grow to around 300.000. That is 4% of the total current housing supply.

This is not directly related to the fact that there is no long term vision in the building industry. However it brings an opportunity to look closer into the current production process of social housing. The components of most houses are all fixed together in a way that is difficult and costly to disassemble it and reuse it in a new building. As a result a lot of materials are lost. The houses which are demolished are mainly because of socially downgraded neighborhoods and financial under performance housing, and not because of the technical life.

There are resources and raw material shortages. The current “linear” economic model where we use raw materials to make products, and don’t reuse has to change.

Despite the circular economy being a happening more and more familiar, the actual implementation is practically unknown. Especially in the construction industry, a conservative industry, the translation of a circular economy seems to be absent.

Construction company Think Wonen wants to make the transition towards a circular business. The aim of this research is to make improvements in the design of the production process of social housing that at the same time facilitates circularity. This is based on the production process of Think Wonen. The transition from a linear economy to a circular economy has an important role.

“A less bad approach is not good enough.”
[Braungart, M., & McDonough, W. 2002]

Keywords: circular economy, construction industry, social housing, industrialized, disassembly, production process

1. INTRODUCTION

1.1 THE NEED FOR MORE SOCIAL HOUSING

The need for more social housing is growing in the Netherlands. This has partly to do with the arrival of asylum seekers into Europe. Nearly 400.000 asylum seekers asked in the first half of 2015 protection in an EU country. Throughout 2014 there have been 562.265 applications. [VluchtelingenWerk, 2015] This is an European scale problem but this report will focus only on the situation on the Netherlands, however the final results can possibly also be applied to other countries.

Appendix F shows the procedure when an asylum seeker enters the Netherlands. The number of residence permit holders that municipalities have to supply housing in the second half of 2015 is about 14.900 exclusive deficit and slightly more than 20.000 including deficit. [Opnieuw Thuis, 2015a]

This research is focused the production of social housing and a case study will show a production of a construction company of social housing for asylum seekers with granted applications.

There is a new reality for the Dutch society, the exceptionally high influx of asylum seekers makes sure that the reception centers have become overcrowded, which requires the COA (Central Agency for the Reception of Asylum Seekers), to accommodate asylum seekers in emergency and crisis accommodations. [COA, 2015] Simultaneously the flow of asylum seekers to a private property within a municipality stagnates, because municipalities have insufficient available housing. The future events whether those people will stay in Netherlands or not is uncertain.

There is a shortage in social housing in the Netherlands and therefore new houses need to be built. This problem is not direct related to the problem of our current linear economy, however this problem illustrated very well how unpredictable the future can be. This brings an opportunity where the production of social housing can become a circular process.

FIGURE 1: ROW TO APPLIANCE FOR RESIDENCE PERMIT [VOLKSKRANT, 2015]

1.2 WHY A CIRCULAR (BUILDING) ECONOMY?

At our current rate of global consumption and waste production, the level of resources required to support us now is about 1,5 earths [Kratochwill, 2013]. In the upcoming years, even more and more resources will be consumed and used by our growing population. Much of these resources is not recycled properly and will end their life cycle as 'waste'. In this line of thinking our economy will change to a Circular Economy (CE), instead of a linear economy. If we look at the building industry we cannot say that this transition is the case. Jan Rotmans, professor 'sustainability transitions at drift', says that it is time to change the conservative and linear building industry [Drukker, 2015]. The building industry that is now based on our current economy of "take-make-use-dispose" called the linear economy has to change. [Ellen MacArthur Foundation, 2012] Houses are built, used and demolish when the requirements of the house change, then the process starts over again. This is not a sustainable model.

In order to achieve a sustainable model it is important to build circular despite the urgency to build more housing for immigrants. Because of this urgency, building efficiently becomes the priority instead of building sustainable. Overly efficient buildings can also be dangerous. [Braungart, M., & McDonough, W. 2002] What social benefit does cheap, efficient housing provide if it also exposes people to more dangers than traditional housing? [Braungart, M., & McDonough, W. 2002]

To achieve a circular (building)

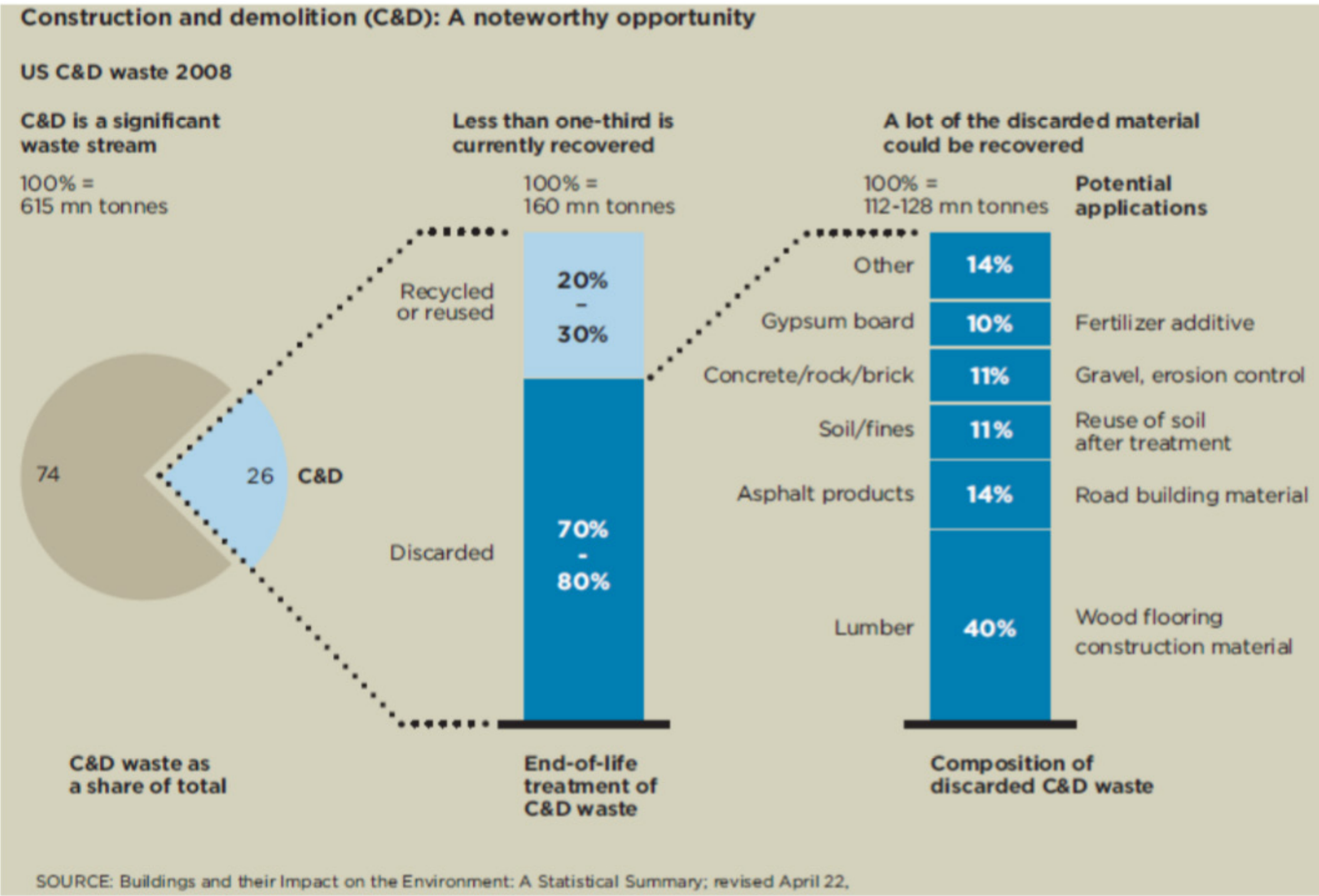


FIGURE 2: CONSTRUCTION AND DEMOLITION WASTE POTENTIAL APPLICATIONS [BICKET, 2014]

economy, we have to fundamentally change our current way of thinking about buildings to solve our current problems and prevent future problems.

The construction sector has a priority for the development of a circular system. The building sector has signficant role in the exhaustion of the planet. The sector is responsible for 50% of the use of raw materials. Besides that, 40% of all energy use and 30% of all water use is related to the building industry. It is responsible for 36% of all CO2 emissions and causes 35% of all waste. [Ridder, 2011] The framework of the CE describes closing loops, hence minimizing the use of scarce or finite materials and preparing current waste for future use. This can give environmental benefits, not by reducing consumption or lowering the standard of living, but by providing new opportunities and inspiration. It creates win win situations for all actors involved in the process.

A CE can lead to material savings of at least 70% in the long run, compared to resource extraction in business-as-usual models. [MacArthur, 2013] Considering the growth in world population and especially the middle class, the total demand of materials required will still rise in a CE, but much slower than without circularity in the system. [MacArthur, 2013]

1.3 Problem definition

There is no long term vision where there is a clear thought on the life cycle of the houses that are going to be build. Houses are fixed and permanent although they maybe need to transform at a certain point. Unfortunately it is difficult to change, adapt or update houses. For this reason a lot of homes end up being demolished or renovated creating a lot of waste. For building companies to perform according to the concept of a CE, it requires them to make use of this “waste” or recycled products as input for their newly manufactured products. Nowadays new mined natural resources are used instead. In order for a building company to start making use of old building components, these components need to find a way back from the end user to the construction company. Making sure building components return to the construction companies and that it can be reused is easier said than done.

FIGURE 3: LINEAR BUILDING INDUSTRY

1.4 Scope and Goal

1.4.2 RESEARCH BOUNDARIES

This research is not aimed to change an entire economic system, or to create a circular building but tries to facilitate the concept of a CE on the scale of a social house.

The target group for the residential units are residence permits holders. Because of the uncertainty of the time that this group will stay in the Netherlands this brings an opportunity to really make the new building reusable and that really fit into circularity.

This research is based on the production process of the building company Think Wonen (TW). The most recent realized project of TW is the case study where the production process of residential units for residence permit holders will be analyzed. Based on this analysis a proposal will be made to make improvements on the production of TW.

The company TW is a new innovative company where they have a recent case where they build high quality social housing for residence permit holders. TW makes homes in a production line off-site. TW makes residential building units in a controlled environment inside a factory and sees houses as a product.

For a building company to be really completely integrated to a CE is a very complex process and it involves a lot of different aspects. This research will describe the complexity of this different problems involved. However the focus is on making a start of how to change some aspects of the production process to facilitate circularity.

1.4.3 RESEARCH OBJECTIVE

The general objective is to improve the production process of social housing of the Company TW so that it can facilitate circularity and become a more circular process.

Changes in the design of TW will be proposed to make the production of residential buildings for residence permits holders in a way that will facilitate circularity. This changes will be based on the case study.

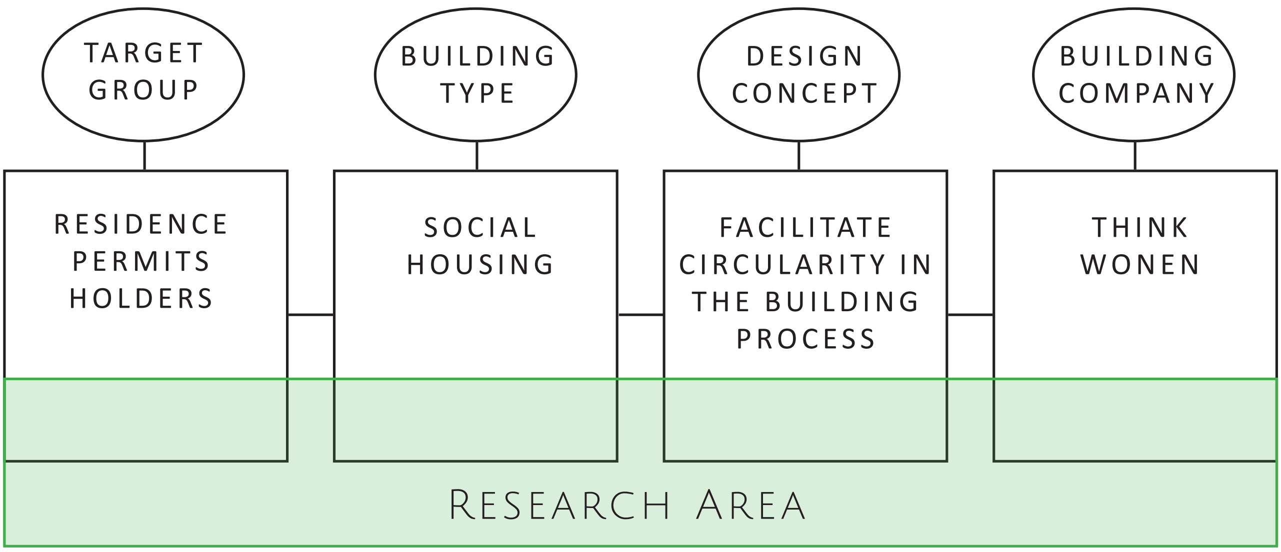


FIGURE 4: RESEARCH BOUNDARY LEVEL

1.4.4 RESEARCH COMPANY

The research is carried out at TW. TW is an innovative construction company. The founder of the company, Mark Spee, gave insight into the research. He has more 25 years of experience as a progressive building contractor. The case study of the research is one recent project of TW and it analysis what is the current production process of TW. The findings are based on TW, however it may be applicable for other companies as well.

1.5 Research question

MAIN RESEARCH QUESTION

How can we improve the production process of social housing of the building company TW in order to facilitate circularity?

SUB-QUESTIONS

1. What is the current production process of houses of the building company TW?

2. What will be the consequences for the design aspects in the production process?

3. What will be the consequences for the technical aspects in the production process?

4. Is it financial feasible to make certain changes to facilitate circularity?

1.6 Approach and methodology

Figure 5 shows the design of the research. It started with two major problems that are not directly related to eachother but still connected. The resource scarcity and waste production is caused by our linear way of production. With the principals of the CE the current process could change. The focus lays on the design and technical aspects but it is important to know how feasible it is looking at the costs of those changes. The changes are based on the production process of the construction company TW.

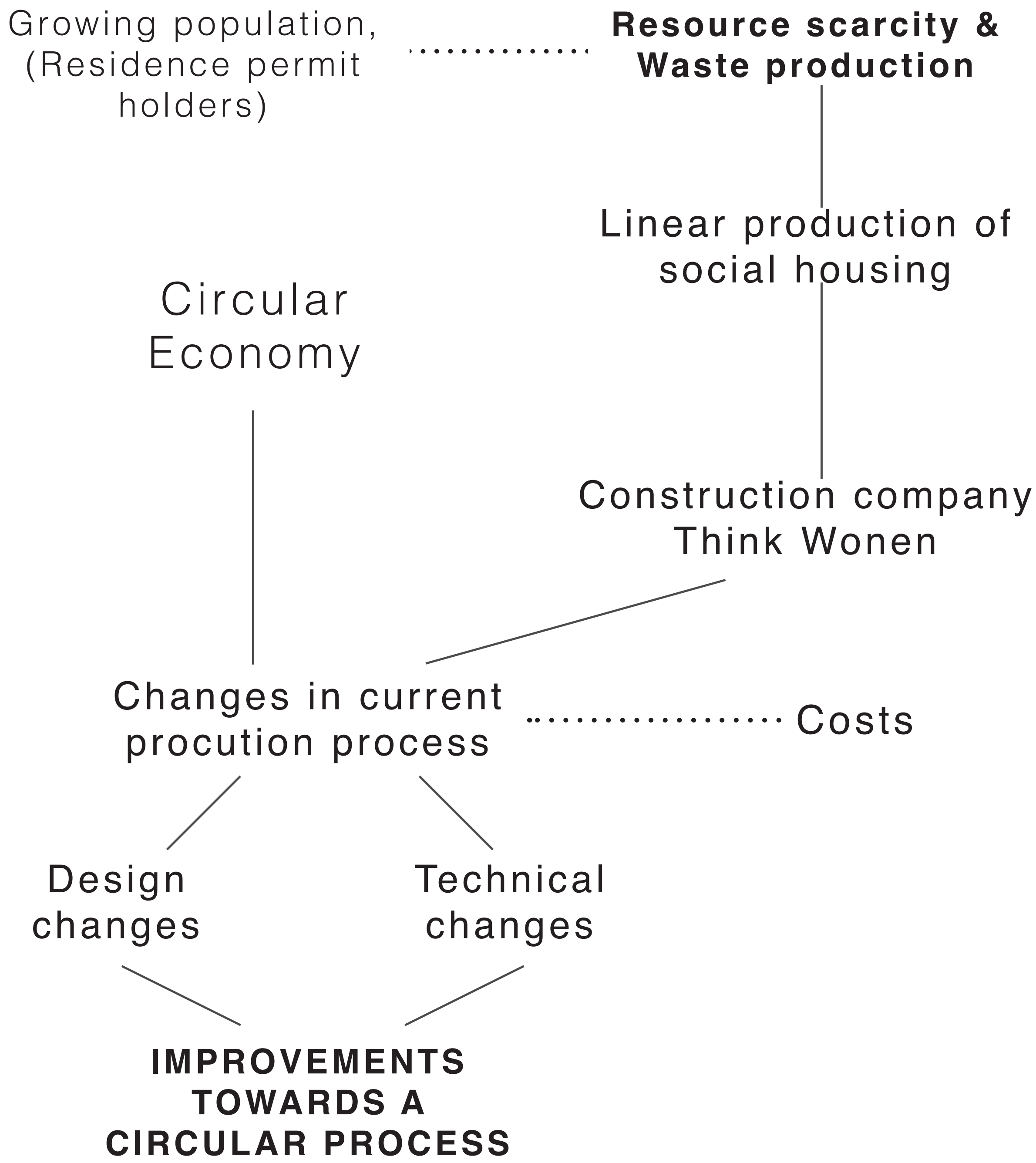


FIGURE 5: RESEARCH DESIGN

In figure 6 the structure of the thesis is shown. The different chapters are organized in three sections: literature research, project research and design proposal.

The literature research is divided into two main subjects: Current production process and circular process. To be able to change the current process , basic understanting of the current way of producing social housing is needed. With this literature research it was possible to formulate clear design, technical and financial considerations to asses the case study. This process has gone back and forward till I was able to create the improvements in for the production process of TW.

The case study is about residential building units that are designed for residence permits holders as target group. The improvements of the production process in based on the production process of this project.

The production line of the company TW will be analysed. After the analysis, the new proposal will be improvements of the current production so that it can facilitate a circular process.

In the end recommendations and conclusions will be given that may also be used in other upcoming residential projects.

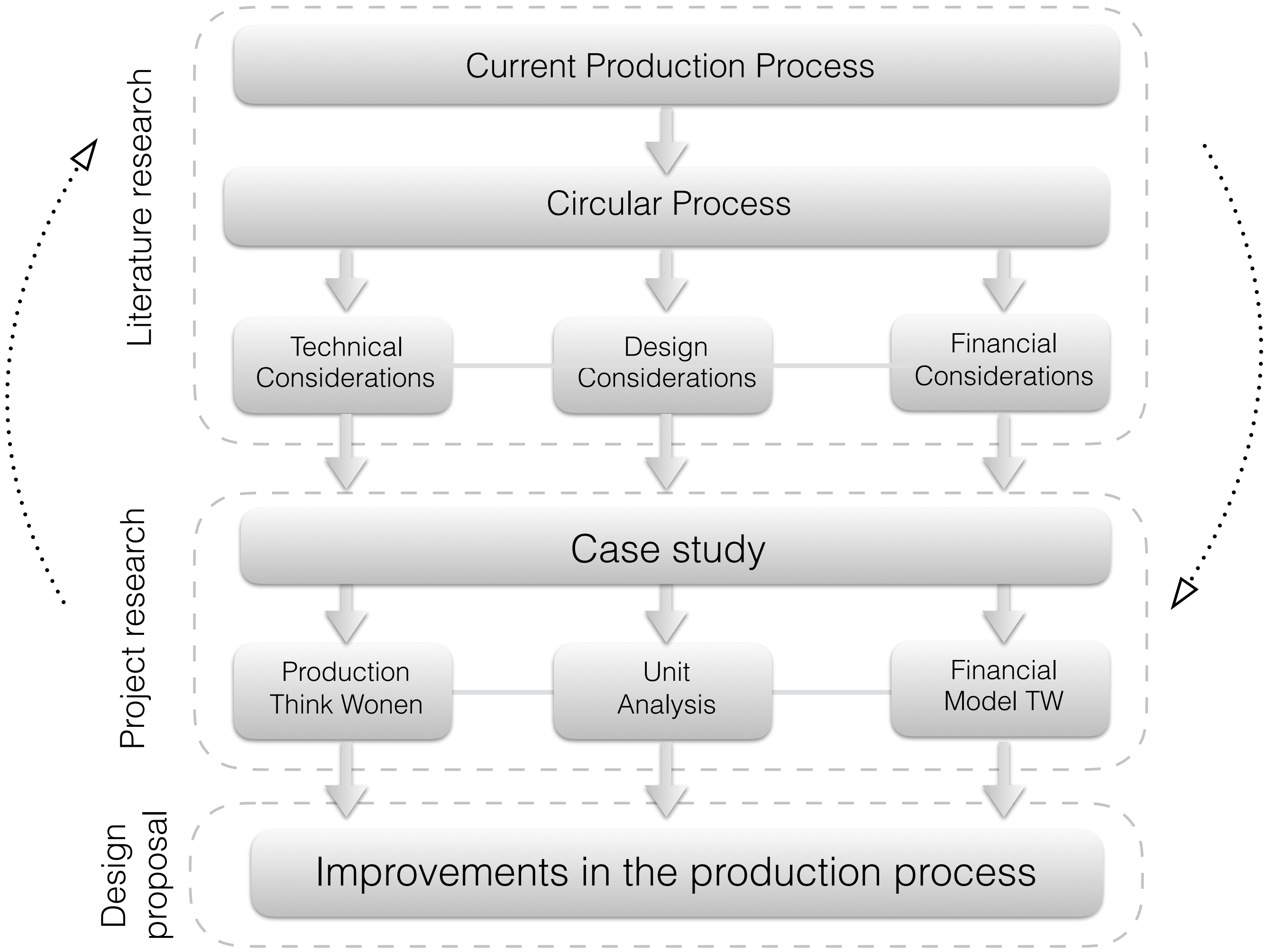


FIGURE 6: STEP-BY-STEP APPROACH, LOGICAL ORGANIZATION SCHEME

1.7 Relevance

1.7.1 SCIENTIFIC RELEVANCE

Buildings are responsible for nearly 40% of our materials and our CO2 production in this planet. Dwellings make more than half of the built stock and will need to be addressed in the coming decades to a non-fossil energy household once the current fossil natural gas for heating is replaced and complemented by energy with electricity and geothermal energy.

There is a continuous search for knowledge concerning designing buildings for high-quality reuse. [Geldermans et al., 2015] The CE is an economic and industrial system designed to maximize the re-usability of products and raw materials and minimizing value destruction by closing circles. It is a synthesis of different ideas by pioneers such as William McDonough and Michael Braungart in Cradle to Cradle and Janine Benyus in Biomimicry. Scientific research is needed for the implementation in practice of these theories and possibilities.

Altough the principles of the CE is based on theories that already exists for a while, the concept of a CE is relatively unknown. There are little practical examples that can be found to proof the theory. By means of this graduation research, a contribution can be made in enlarging the knowledge about pratical applications of the CE in the construction industry.

1.7.2 SOCIETAL RELEVANCE

The future material demand is difficult to predict and therefore there is a risk in security of supply of materials. Resource extraction is expected to double from 1980 to 2020, and when continuing with business-as-usual business models, will have tripled in 2050 compared to the current situation. This will create resources scarcity. The concept of CE prescribes a solution to possibly solve these problems. This research desires to assist in taking steps to solve the problems around resource scarcity.

2. LITERATURE RESEARCH

2.1 Current production process

Nowadays there are different ways to produce social housing. The need is growing so fast that building fast is necessary. One way to accomplish that is by building temporary.

Building off-site in a factory is common in the Netherlands. Construction companies like Volker Wessels, Ballast Nedam and CascoTotaal are already building full production houses in a factory where it is produced in parts or in modules. (Clahsen, 2016) TW also produces the houses inside a factory. Although the process is changing to a more efficient process by building off-site it is still a linear process. This chapter will discuss the current way of building social housing.

2.1.1 TEMPORARY HOUSING

Temporary housing is not a new phenomenon in the urban context and has been around as long as humanity, thinking of the shelters of nomads and early hunter-gatherers [Bishop & Williams, 2012]. According to Bishop and Williams [19, 2012] a city is always evolving is and is never an end state. This also applies to a scale of a building, house. A house is also awalys evolving and it is not a permanent object.

As stated by Opnieuw Thuis [2015] there are different types of temporary residential building units that can be used for housing of the residence permit holders. The more luxurious like the Heijmans One, but also the very basic like the container houses. The principle is a box of standard dimensions, which can be transported as a whole and is stackable. The bottom of a unit determine how and where it can be placed, 20 cm concrete has other conventional features as a wooden floor. Equipped with a skeleton or self-supporting walls of steel, aluminum, plastic, wood, sandwich panels it all happens. They may or may not feature an extra exterior finishing. There is a choice of interior available, with standardized connections for water, electricity and sewerage. To make housing units stackable, they must have sufficient strength and can be safely anchored. In some systems that is up to 12 stories high.

Every building should be durable, adaptable, thermally efficient, weatherproof and comfortable. These five general requirements are critical for a sustainable property [Douglas, 2006]. After looking into 24 examples of temporary housing solutions (see appendix A), none of the examples met one or more of the five general requirements. Every building is actually temporary. The difference is in the quality of the requirements. What makes a house temporary is the fact what kind of permit it gets. A temporary permit to build is more easy to get in contrast to a permanent permit. At the end of 2014 the legislation for a temporary permit changed from 5 to 10 years. [Sbt. 2014-333] This creates an opportunity for temporary housing to have a better quality. Temporary houses are more adaptable. And have a better chance of meeting its future requirements.

There is still a distinction today between permanent housing and temporary in the way of thinking in construction. The current way of thinking is static, this is supported by the fact the goals is keeping the building as much as possible in its original state by doing maintenance [van Nederveen & Gielingh, 2009]. The kind of thinking that buildings are permanent needs to change.

The requirements of the users and owners, but also environmental, social and technological requirements will endlessly continue to evolve. Van Nederveen & Gielingh [2009] state: “A building should not be seen any longer as a static object that meets only initial needs, and which ignores the idea that life has an end. A building must be seen as a process, being capable to meet changing demands.”

2.1.2 OFF-SITE FABRICATION

Unlike the innovative car industry, the traditional building industry has not changed so much during the last years. According to David Gann [1996] the housing industry can learn a lot from the advanced manufacturing techniques developed in the car production. The traditional onsite building systems should change into a more smart, fast and sustainable system. With industrialization a vast gains in productivity and quality is archived in many manufacturing industries, we cannot see similar progress in the building construction industry [Warszawski, 1999]. Warszawski [1999] believe that the solution to this problem is when industrialization and automation replace manual labor in all phases of the building process.

In the first half of the 20th century influential architects such as Le Corbusier, Walter Gropius, Bemis and Buckminster Fuller really believed in the idea of industrialization of the building industry [Gann, 1996]. Buckminster Fuller argued that the production of buildings should be like to that of cars, he criticized the traditional onsite production that each house was treated as a pilot model for design and said that it belonged to the Middle Ages [Gann, 1996].

If we look at what kind of building techniques that is used nowadays, off-site fabrication encompasses a large part of them, with perhaps the building brick being the simplest prefabricated component in use throughout most of the world. On the other hand you can also think of a whole building being prefabricated [Gibb, 1999].

2.1.3 INDUSTRIALIZED HOUSING ADVANTAGES

The benefits of off-site production are mainly dependent on project-specific conditions and the combination of building procedures being used on a project [Blismas et al., 2006]. There are three main advantages in off-site fabrication. Building off-site reduces the construction labor onsite, it decreases the construction time to a minimum and there is a better quality of the building components [Warszawski, 1999]. Therefore the conditions in a factory assure better quality control, thereby avoiding some unnoticed defects that require later repairs [Gibb, 1999].

Ever since Henry Ford developed the standard production line for car manufacture, leading European and North American builders, manufactures and architects have been tempted to produce houses in factories [Gann, 1996]. Gann [1996] mentions another three advantages of manufacturing off-site over traditional craft is that unit cost decreases as production costs rise faster than the volume of the materials being processed increases, the technical possibilities to develop and deploy capital equipment and the opportunity for tighter managerial control [Gann, 1996].

The benefits that Warszawski mentioned are closely related to the benefits of Gann. They are results from eachother. Innovation and new product development are important sources of competitive advantages [Tushman et al., 1997]. So prefabricated homes are not only faster and efficient to built, it has also a better quality than traditional construction like stick-built [Hutchings, 1996].

For the industrialized housing large elements of houses are constructed in factories. This can indeed speed up the process, since manual labor is reduced. Especially the construction time on-site is reduced, which has multiple advantages. First of all the labor costs can be reduced. Besides that the nuisance can be limited, which will result in less complaints from the surrounding residents. This causes less delay for construction projects, since complaints from residents can result in a lot of time spent on meetings and sometimes even lawsuits. This can again result in the reduction of costs.

Another big advantage of industrialized housing is the integration of different building layers. Since all elements are built in the factory, all building layers will have to be integrated there. The supporting construction, the climate system and the finishing are all produced in the same factory. This asks for a lot of communication and collaboration between different professionals and therefore a change in the mindset of people working in this sector.

However, if the collaboration does happen, great results can be achieved, since at industrialized housing the integration will be implemented from the beginning of the project. This will also positively influence the management of the project, which will be a lot easier if there is collaboration between all parties from the beginning of the project.

The fact that the elements of the houses will be standardized to certain extend makes it easier to replace elements. This makes the maintenance of the buildings easier, but also gives the opportunity to make changes when requested in later phases of the building life cycle.

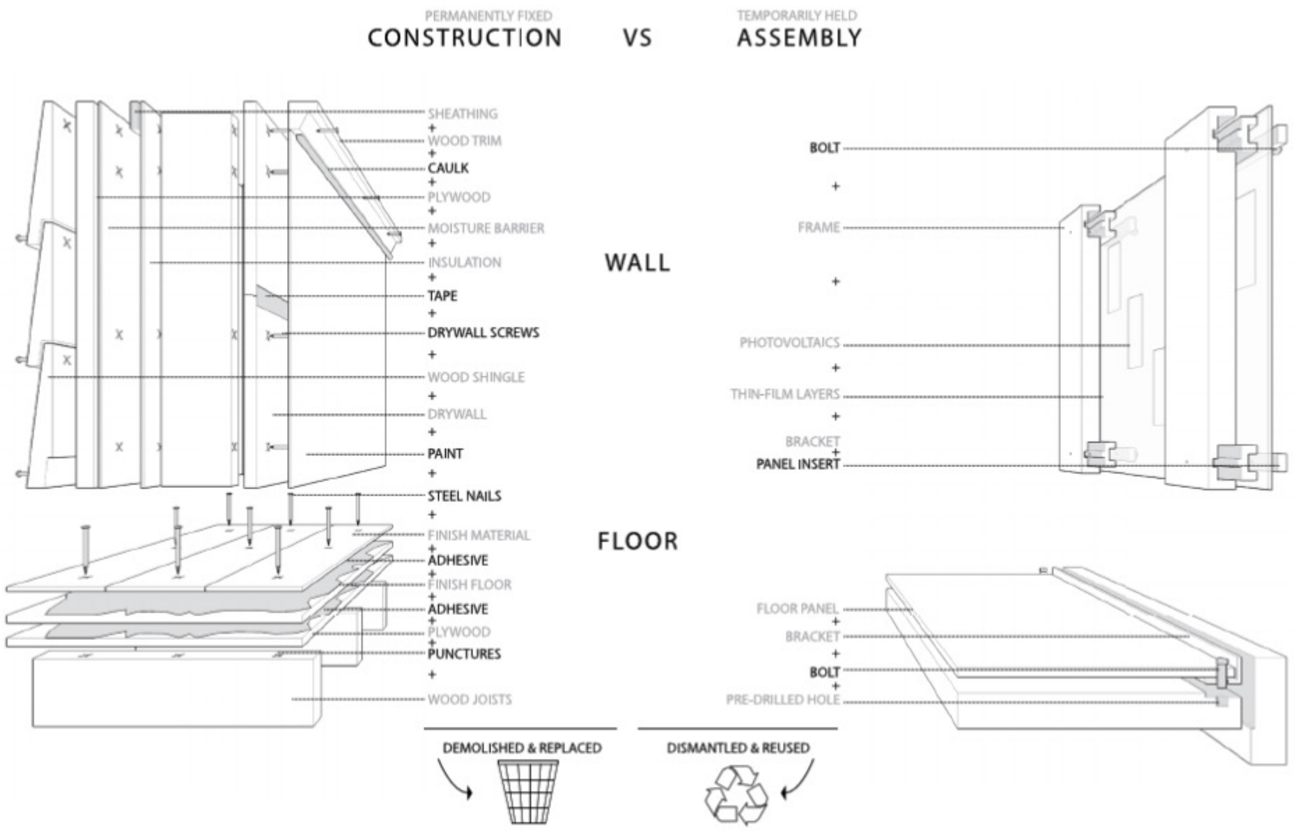


FIGURE 7: TRADITIONAL CONSTRUCTION VS INDUSTRIALIZED BUILDING [SMITH, 2010]

If for example a resident wants to change something to his home after a couple of years, the same manufacturer of the home can easily replace parts.

The last big advantage concerns sustainability. This is a major point of attention in the building sector nowadays, with good reasons. Industrialized housing can reduce the use of materials, since calculations on the needed amount of materials can be made more exact, which also results in a reduce of waste. The energy use will be lower, since less machines will be used on site, while the energy used by machines in the factory can be optimized. The off-site production results in less transportation forth and back from the construction site, which reduces the CO_2 emissions.

According to Durmisevic [2006], the main potential of industrialised approach to making buildings can be summarised by the following:

- Freeing up of many of a building's functions and altering them from fixed to less dependent conditions,
- Greater quality of buildings
- Greater match between requirements and materialised solutions,
- Greater quality of life (that match buildings to individual preferences),
- Better control and more efficient use of resources,
- Greater possibility to reconfigure structures according to new demands,
- Diversity,
- Development of assembly/disassembly techniques, and
- Extension of the designer's vocabulary, expressed in combinations of different, and materials for the building's structure.

2.1.4 INDUSTRIALIZED HOUSING CONSTRAINTS

Despite the benefits mentioned in the previous subchapter the share of industrialized building in the total output is not significant increasing mainly due that the technology, organization and design of prefabricated building systems never became an integral part of the professional knowledge of engineers and architects, obtained as other subjects through a regular academic education [Warszawski, 1999].

However, industrialization and standardization of housing can be very rational, based on efficiency can it lose the attention towards a humane living environment. The excessive tendency toward repetitiveness and standardization in public projects resulted in monotonous buildings that very often turned into dilapidated slums within several years [Warszawski, 1999]. The image of industrialized dwellings as socially inferior housing solutions was further reinforced by production defects in building elements, which are quite frequent in the initial stages of prefabrication [Warszawski, 1999].

The building surrounding has than no identity if every house looks the same way. An answer to this problem could be an evidence- based design where an architect evaluates a design, and variations of that design, to see if they contribute to human wellbeing [Salingaros, 2015].

2.1.5 CONCLUSION

In order to achieve a circular process the realization that every building is temporary is important, because then this thought can be taken into account already from the beginning at the design phase.

The current production process of houses is a linear process. The current production is industrialized where the most of the production of houses happens off-site. This is also the case for the construction company TW.

Although the current process is linear the transition to an industrialized process of building houses has advantages to eventually become circular. Building off-site does not only make the production efficient and faster but also more sustainable because of the controlled environment and it is easier to convert to a circular process. This has to do with the standardization of the different components of a house and the integration of different building layers. However the challenge remains of creating a non-repetitive design where there is still architectural qualities.

Building industrialized with the thought that nothing is permanent is the first step towards a circular process. TW wants to change to a circular process. Being a relatively small construction company they can make changes fast and with little investments compared to big construction companies. In the next chapter a circular process will be described.

2.2 Circular process

The opposite of a linear process is a circular process. A circular process is based on a CE where the use of products are in cycles. This chapter describes the principles of a CE, where it comes from and shows the connection with the construction industry.

2.2.1 What is the CE

In contrast to today's largely linear, 'take-make-use-dispose' economy, a CE represents a development strategy that allows economic growth while aiming to optimize the chain of consumption of biological and technical materials. [Bicket, 2014] The idea is to keep materials circulating in the economy for longer without loosing value . Therefore re-designing industrial systems and encouraging cascading use of materials and waste is necessary.

The CE is not a new phenomenon and it is based on different theories. The CE is a fusion of existing theories in the field of sustainability and system change then a new concept that has received some new attention thanks to successful marketing, largely led by the Ellen MacArthur Foundation (EMF).

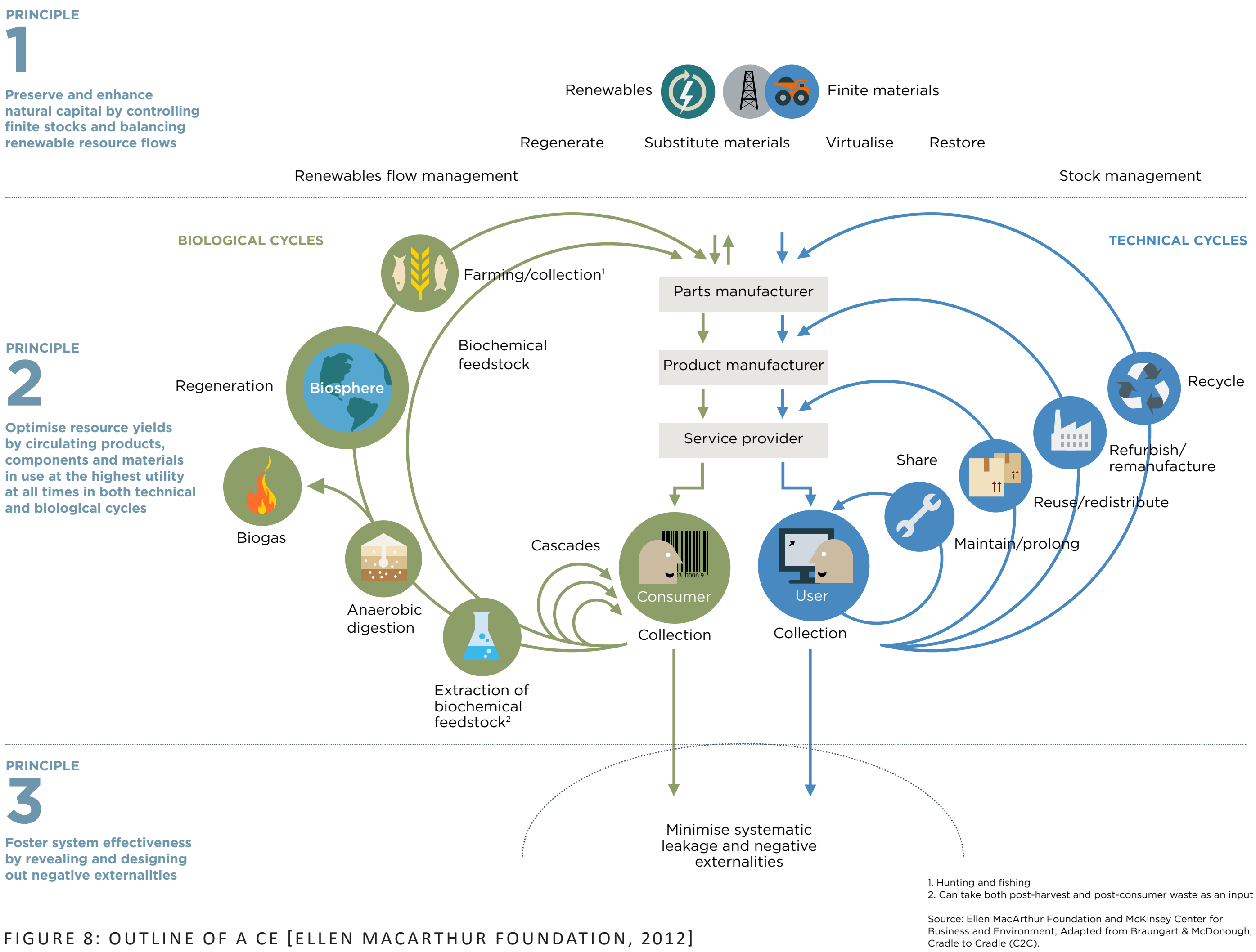


FIGURE 8: OUTLINE OF A CE [ELLEN MACARTHUR FOUNDATION, 2012]

The CE is based on a few simple fundamentals [Ellen Macarthur foundation, 2012]:

- Design out waste
- Build resilience through diversity
- Rely on energy from renewable sources
- Think in systems
- Waste is food

The digram of the Ellen Macarthur foundation (see Figure 8) shows the way materials can flow. The scheme shows the distinction between biological and technical cycles. In the case of houses we can say that it is more a technical product because it consist largely of metals and construction materials that are technical nutrients. But here is also a significant role for bio-based materials such as various kinds of wood.
There are in the scheme there basic principles. The first principle is to preserve and enhance natural capital by controlling finite stocks and balancing renewable resource flows.

The second principle is to optimize resource yields by circulating products, components and materials in use at the highest utility at all times. The are different technical cycles. The maintenance of a product is the process of keeping it in good condition, without changing user. To reuse/redistribute is to reintroduce a product for the same purpose and in its original form, following minimal maintenance and cosmetic cleaning. Refurbishment is the process of returning a product to good working condition by replacing or repairing major components that are faulty or close to failure and making cosmetic changes to update the appearance of a product, such as changing fabric or painting. Re-manufacture denotes the process of disassembly and recovery at the subassembly or component level. Functioning reusable parts are taken out of a used product and rebuilt into a new one. This process includes quality assurance and potential enhancements or changes to the components. Recycling is the process of recovering materials for the original purpose or for other purposes, excluding energy recovery. The materials recovered feed back into the process as crude feedstock. If this results in a reduction in quality it is often described as down-cycling. Processing to improve material or product quality is described as up-cycling.

The third principle is to foster system effectiveness by revealing and designing out negative externalities.

The term CE already reveals what it really means for the building industry. There are two things that are important. First circular, in order to make the different materials have different life cycles and change you need to be able to design in a way you can easily disassemble these materials. Stewart Brand [1994] distinguishes six different layers within buildings. Each layer and the components within have their own technical, functional and economic lifespan. So there is a need to Design for circularity.

Modular or standardized components, design for disassembly, design for pure material-flow and optimization in production processes to reduce waste will become main topics in designing a building within the CE. The second term in CE is economy. It is necessary that companies have a profitable business case if they change the way they work into this new concept. Fiscal incentives including taxes, charges and levies can be applied to help the CE accelerate.

The principles of EMF as presented before are not new. On the contrary they are based on earlier visions and theories. The list in Appendix G, the CE framework, presents the roots of the principles of CE according to the EMF. Figure 9 shows the different theories in a time line.
All theories have a similar starting point: The linear economy. They all imply the same: with the implementation of that theory the destructive linear economy will be turned into an economy which relies on renewable sources and decreases the burden on the scarcity of natural resources. Almost every principle mention before is covered by the principles of a CE. Although the CE is not a new concept the full transition is not yet in sight in the building industry and there is still a lot of improvements that can be done.

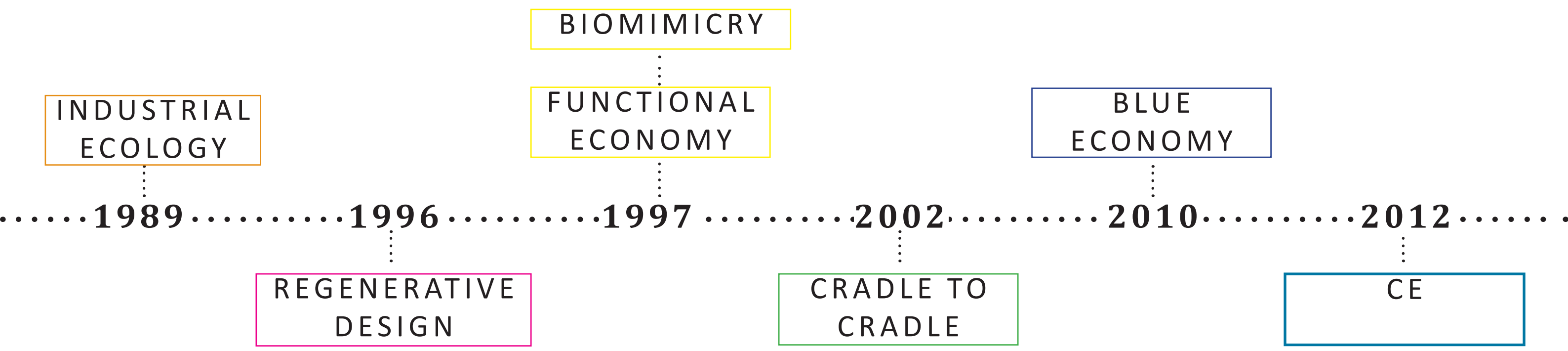


FIGURE 9: THE FRAME WORK OF THE CE IN TIME LINE

2.2.2 FROM LINEAR TO CIRCULAR

The step from linear to circular has a high complexity because of all the different linked domains and aspects. [Geldermans et al., 2015] There is the social aspect, because when the product is really good the user will have the best experience. The technical aspect, is this the best material to use and can I disassemble it easy and low cost. Design, how to make sure that there is architectural quality. The finance is very important, specially for the companies that will have more responsibility for the product. Therefore the legal part is also important, who is the owner and how to asses the long term vision. But also the organization behind it, how to collect the products, think of the logistics. Contextual, nuisance and so on. To get from a linear process to a circular there are a lot of aspects involved. To get the building industry into the CE is a complex concept encompassing a range of materials, products and actors, different stages in value chains, with varying potential for circularity. [Bicket, 2014]

Domain	Example of aspects
Social	User-oriented, Employment, Health and Safety
Technical	Purity, Recycling, Connections
Design	Aesthetics, Division, Diversity
Financial	Total Cost of Ownership, Life Cycle Costing, Profit
Legal	Ownership, Extended Producer Responsibility, Standardization
Organisation	Communication, Logistics, Governance
Contextual	Environment, Nuisance, Contextual Integration

TABLE 1: LINKED DOMAINS AND ASPECTS TO CE [GELDERMANS ET AL., 2015]

Nowadays almost every building project occurs in a linear way, the result we throw away a lot of materials. The building industry is seen as an inefficient industry with high failure costs, little profits and a large consumption of resources [Gijsbers, 2011]. In a circular process on the other hand, products and materials are not wasted. Products and materials are recovered and used again. This process can be called a circular flow. In the current building industry there are three factors that make it difficult to circularly work with materials: the poor information transfer, the fragmentation of interests and the mix of products and materials. [Zuidema, 2016]

To change the current production process to a more circular process there is a need to understand what are circular flows in a house and what does it consist of. Repairing and maintaining the units preserves most of its value. If this is not possible anymore, individual components can be reused or re-manufactured. This preserves more value than just recycling the materials. Focusing on the reuse of Units, Components and Elements preserve more of a product's integrity, complexity, and embedded labor and energy.

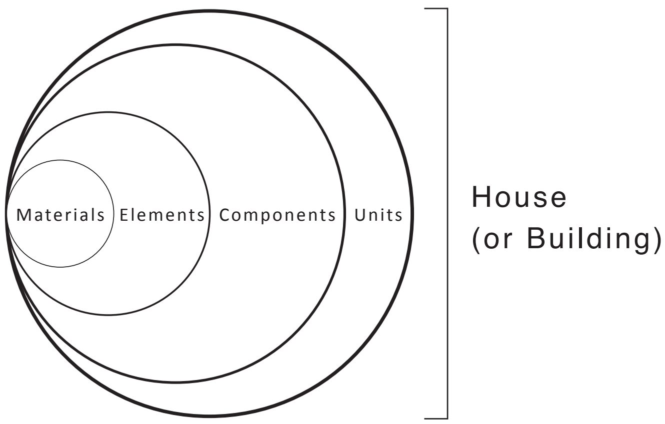


FIGURE 10: INTERPRETATION OF A HOUSE

Each prolonged cycle avoids the material, energy and labor of creating a new product or component. Uncontaminated material streams increase collection and redistribution efficiency while maintaining quality, particularly of technical materials, which in turn extends product longevity and thus increases material productivity.

In a CE products, components and materials are subjected to use and reuse in order to keep up with the self-sufficient character of that CE.

Reuse on the level of an unit is associated with maintaining all components , elements and materials of an unit and it simply involves replacing it or change of its user.

Reuse on the level of components is associated with keeping all elements intact and involves the disassemble the components of an unit and reassembly into a new unit.

Reuse on the level of materials is associated with the abolishment of a component or entire product. It releases the materials the elements are consisted of. In case these are able to regenerate the materials can be regenerated by the ecosystem the material is part or alternatively they are recovered.

Material reuse is relatively less ideal, as potentially these materials can potentially undergo functional regression when they transition from material resource to material waste.

2.2.3 WHO ARE THE ACTORS IN THE HOUSING MARKET?

There are many different parties, which are also involved in the building process in various ways. The raw materials suppliers are active on a global raw materials market. They supply to the manufacturers of construction products, who sell their products directly or through wholesale to contractors. Those contractors handle the construction of a building commissioned by real estate investors and housing associations, on the advice of architects and other consultants. Contractors are checked during the construction on behalf of the client, but the day after completion of a project the contractors have no more responsibility for the project. The clients, the real estate investors and housing associations, mainly want to make their investment secure. They see no financial interest in the processed products and materials. And then there are the users who live in buildings, in this case the Residence permit holders, who are completely unfamiliar with the subject. Figure 12 shows the current state of events as explained.

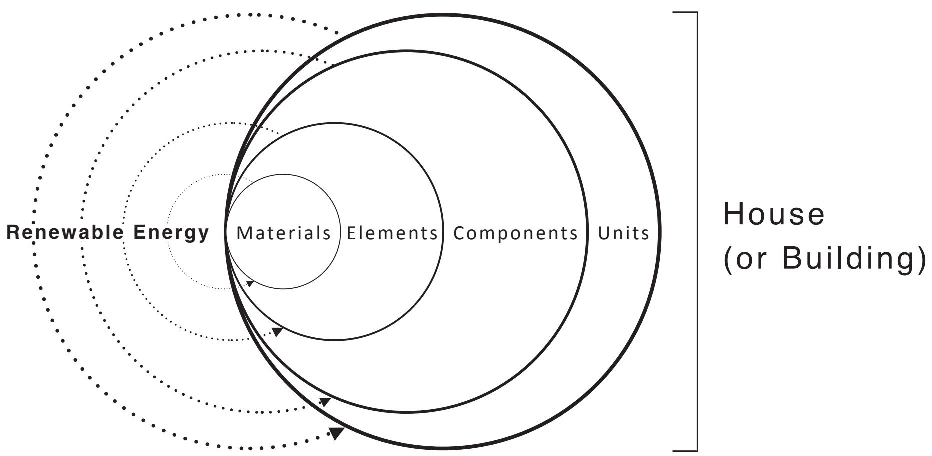


FIGURE 11: CIRCULAR FLOWS OF A HOUSE

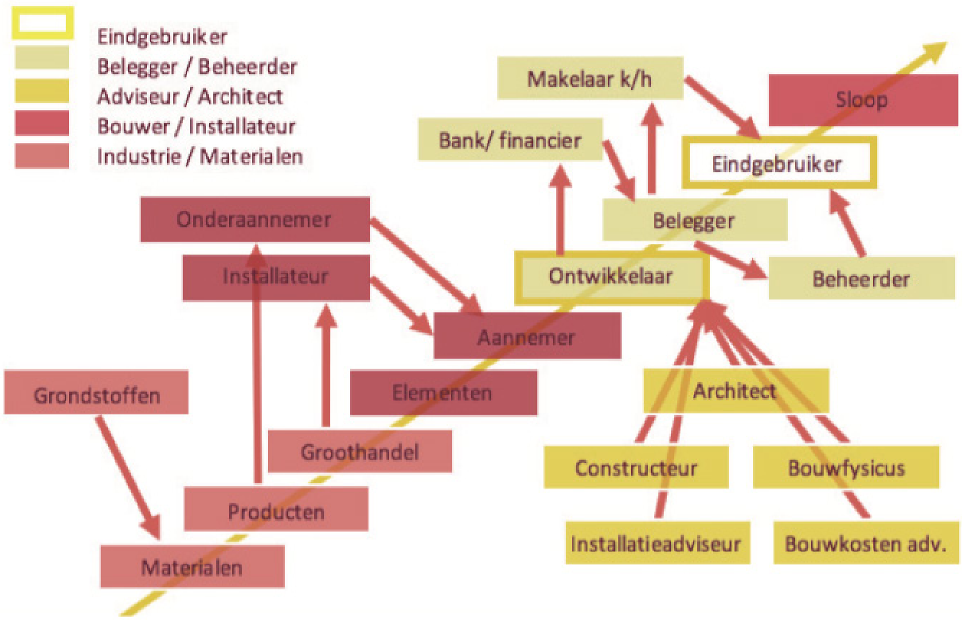


FIGURE 12: CURRENT LINEAR ORGANIZATION OF THE BUILDING INDUSTRY [ZUIDEMA, 2016]

All these parties often work only once of a few times on a project together. In this system, the cooperating parties do not learn from eachother and from the process. The needs and revenue of all these parties differ too much from eachother to easily reach a sensible exchange of information. That is inconvenient, if the next time you want to apply what you learned together again. In this way we lose valuable information and we stay every project at the same level instead of making great progress. But that could be different when we organize the process in a circular way where parties stay involved during the use and after. Figure 13 shows the circular organization where the parties stay involved and exchange information with eachother.

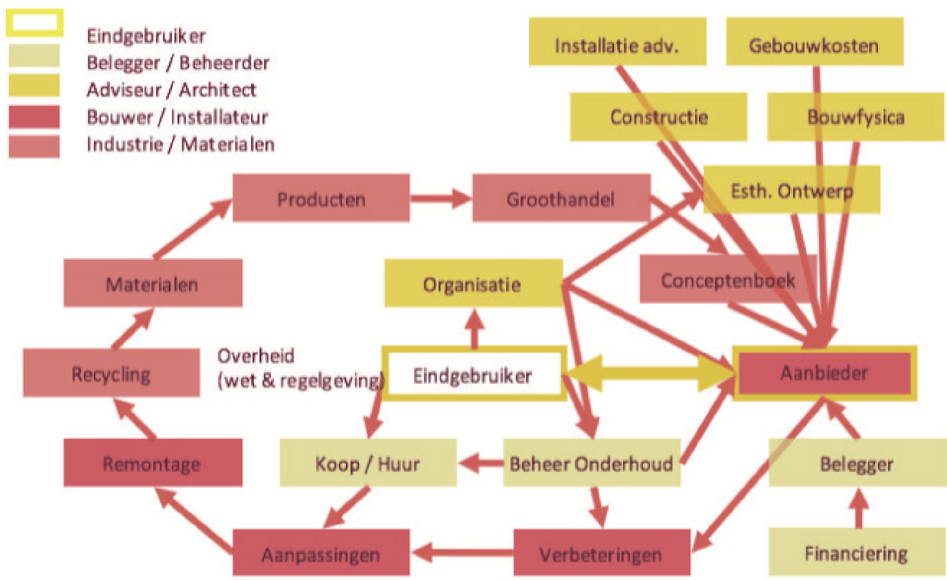


FIGURE 13: CIRCULAR ORGANIZATION OF THE BUILDING INDUSTRY [ZUIDEMA, 2016]

MUNICIPALITY

The municipality is the initiator. It makes the regulations and give assignments for housing associations to provide social housing.

The government could get involved by changing laws and regulation in order to stimulate reuse, changing tendering processes, and subsidies.

DEVELOPER

The developer is involved from a financial perspective in the building process. He is involved with the building, because of the financial incentive it produces, resulting in a financial yield on the investment.

HOUSING ASSOCIATION

In this case study of this research is the Housing association also the developer. However it does not have only a financial incentive. It also have a social incentive and goal to provide affordable housing.

CONTRACTOR

The contractor or construction company or building company is the stakeholder that during the development of the building are involved in the process of making the product, the houses. The contractor can be seen as the technical side of the development. He makes sure the product is finished and ready to be used.

ARCHITECT

The architect makes the design of the building looking from an aesthetic point of view. He also ensures that the design fits into the urban context.

USER

The user will be in this case families that are residence permit holders. They just received their first house in the Netherlands and they are going to live there.

By putting all those actors into perspective it is possible to see the problem. The problem when there are many actors involved is that is very easy to blame someone else for anything that goes wrong. In a CE everyone has to contribute for it to work. Every stakeholder should start taking responsibilities.

2.2.4 CONCLUSION

The building sector produces ‘products’ with a long life cycle. This makes the issue of waste less visible. Furthermore it is more difficult to close the loop around wasted/demolished building materials. In sectors where goods move faster, waste streams can be reconnected on shorter term.

To facilitate circularity first clear understanding of what the CE means is needed. The step to a circular process is complex and it involves a lot of different disciplines. Creating circular flows in a house is necessary for a house to become circular.

A lot of different actors are involved in a building process and the organization is in a linear way. By changing the organization of the actors we can create a circular organization that will facilitate circularity. A construction company can have a major influence by the trasintion by setting the standard in the way of building.

Multiple definitions exist of a CE. The Ellen MacArthur Foundation is seen as the leading institution on CE, and her definition [EMF, 2012] is seen by many as the correct definition.

To create a circular building industry, buildings need to be able to disassemble components to keep natural resources in the technical loop. A building may not be seen as final combination of components and elements but as a living system.

2.3 Technical considerations

To complete the transition from a linear to a circular production there are technical aspects that needs to be considerd. This chapter shows some of the technical aspects involved into the transition. There are three considerations that are going to be discussed in this chapter, the lifetime of housing, the building layers and the disassembly of a house.

The essential element of extending the life cycle of buildings and the materials they consist of, includes designing the ability to change all degrees of technical composition of a building. This transformation, indifferent of the materials used in the building, is related to disassembly and reconfiguration of elements. There has to be a new form of design approach to achieve this. The focus must lie on the long-term performance of a building and finding a match between its technical and functional composition.

2.3.1 SOCIAL HOUSING LIFETIME

The lifetime of a building depends on different factors. Many assume that buildings last longer when made of more durable materials. [Durmisevic, 2006] However, hence demolition and resulting in material and energy losses shows that [Durmisevic, 2006]:

"1. due to the frequent functional changes the 'use life cycle' of materials is often shorter than the 'technical life cycle' of materials;
2. Materials are often integrated into a fixed assembly; the replace ability of one element means the demolition of others;
3. The end of the life cycle of buildings is associated with demolition and waste generation."

In the built environment it often happens that buildings become empty and non-functional although from a technical point of view their expected lifespan can be decades longer. This happens because the needs of the user change in time. "A traditional building can be seen as a materialized solution for user needs that existed before it was constructed." [Van Nederveen & Gielingh 2009] This often results in early demolition. The demolition of buildings, which are still in good condition, is hard to justify from an economic and environmental point of view. Destroying these technical sufficient buildings enlarges the influence of the building industry to the current obstacles the world is facing, having an effect on environmental impact due to waste production. This causes the construction industry to be a large producer of waste. Hereby is the exhaustion of the natural resources is also a problem.

The end users of a building have certain specific requirements. These specific requirements are always changing. When a building does not meet those requirements anymore it may loose its function. The users who are no longer pleased with their building have to think of an solution. This results often in a renovation of the current building or change to a new building that does meet the new demands. These solutions are energy consuming, and have a negative influence on the environmental and social impact of the building industry [Huffmeijer & Damen, 1998].

According to Jong [1997] the lifespan of buildings depends on: technical, functional and economical lifespan. Those three main aspects are related to eachother in which the shortest is responsible for how long a building will be used. Figure 14 shows the functional, technical and economic lifespan in three schematic graphs. The life-time that leads to a unusable building should be addressed. This way it is possible to optimize the total life-time of a building. The technical lifespan can be defined as: 'the period in which a building is sufficiently reliable and can continue to perform the desired functions.' [Huffmeijer & Damen, 1998] This is the period that a building is still adequate to the technical requirements needed. These requirements might come from building codes and or also from certain needs of users.

Because a building is constantly aging and building parts decaying as the time continuous, the technical performance of building decreases in time. This process cannot be stopped, however it can be controlled.
The technical life-time of a building can be increased by replacing the components that are not performing well. But also when the specifications changes in time some components that then become outdated need to be replaced. Those two factors state the technical life-time of a building.

The functional life-time is mainly determined by the end users. When a building does not meet the functional

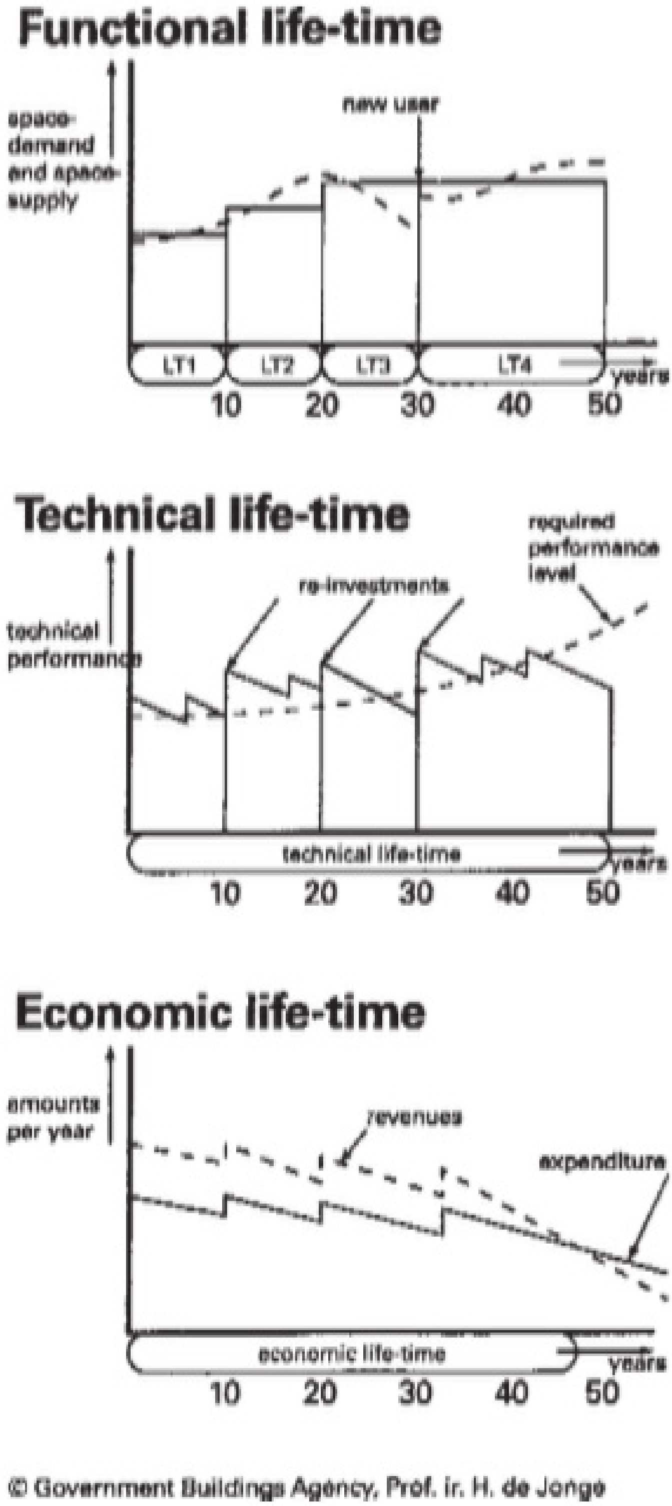


FIGURE 14: FUNCTIONAL,TECHNICAL AND ECONOMIC LIFE TIME [JONG, 1997]

demands of the end users the functional life-time ends. This often happens before the end of the technical life-time. The consequence of this is that the building becomes non-functional, while it is still in a good technical condition. This can be prevented by the realization of an optimum functional flexibility. [VROM, 2004] The flexibility that is required in de design depends on the type of changes and period in which the changes needs to be done. According to Gijsbers [2011] changes inside the building happens typically in a short term.

The third factor according to Jong [1997] that determines the life-time of a building is the economical factor. The lifespan ends when the operation of a building is no longer profitable.

The demolition decision is an important indicator of lifetime homes. Other reasons for demolition besides the three previously discussed could be oversupply of property type and because of urban planning reasons. [VROM, 2004]

If we look specifically to corporation houses or social housing, they appear to have a disproportionate higher risk of being demolished compare to private property. Social housing properties have approximately 12 times more chance to be demolish than private properties. [VROM, 2004] This difference in demolition chance is all the more remarkable because the KWR check (Qualitative Property Registry). It shows that the technical quality of housing association homes is better than that of similar property type that are not social housing. [VROM, 2004]

Given the current construction methods and current materials there are constructive seen to be expected no problems with new construction. The current Building Act 2003 ensures that future housing constructive seen to have a long life potential. When demolition can be avoided for other reasons, the quality of the hull will not give rise to demolish housing prematurely. [VROM, 2004]

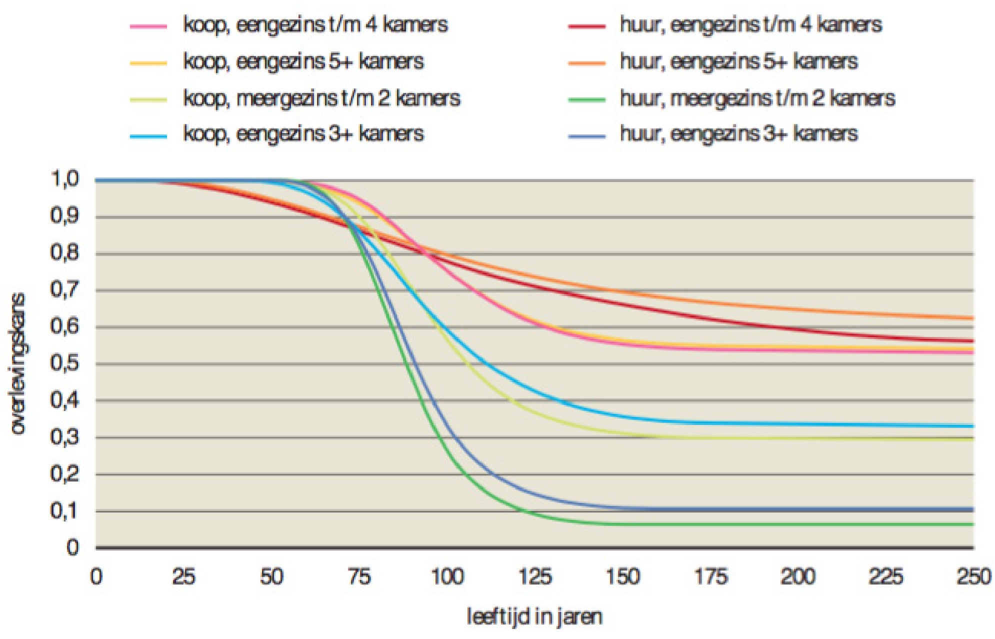


FIGURE 15: CHANCE OF DEMOLISHMENT [VROM, 2004]

2.3.2 BUILDING LAYERS

Stewart brand [1994] divides the building into 6 building layers. (See Figure 16) The site, structure, skin, services, space plan and stuff. Although further hierarchical subdivisions can be made, the structural layer, skin layer, service layer and space plan layer are adopted at this point in the study. By making this distinction in life span between layers, we can leave natural materials cascading while retaining the value of technical materials.

Stuff, which are, all things that switch around daily to monthly, such as "chairs, desks, phones, pictures, kitchen appliances" have been left out as they're considered part of the assessment of products from the consumer products industry.

The site, however, is indeed an important part of the real estate & construction industry. Different from the mining industry, for whom the site can be seen as a finite resource that produces flows of materials, the real estate sector and construction industry refers to the site more as a geographical location. The location is eternal, therefore continuous by definition and produces, from the perspective of the real estate & construction industry, no material flows.

Every building should not be seen as a static object but as a dynamic set of subsystems. Steward Brand proposed that buildings should be seen as 'learning objects or processes' Brand gave insight into the problem of buildings that were not designed for change; components with a long technical or social lifespan were being integrated with components with a much shorter life span.

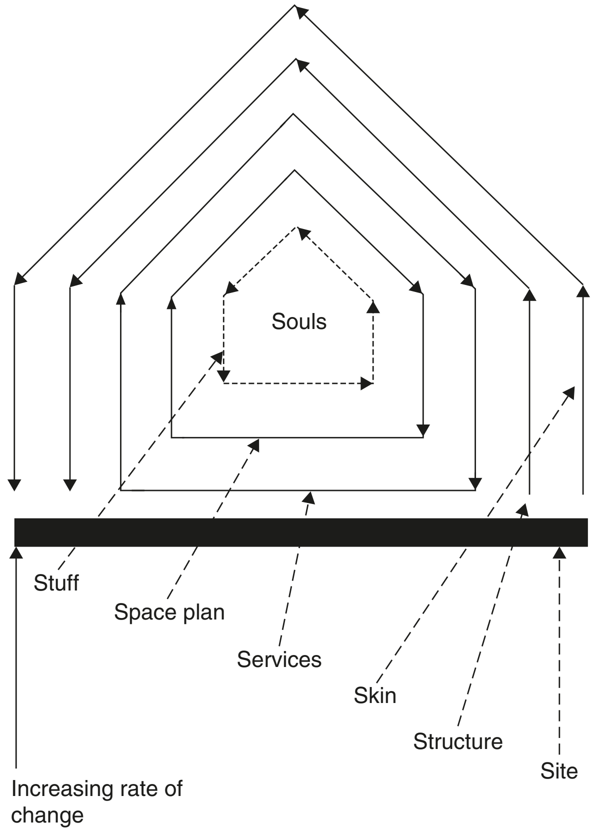


FIGURE 16: BUILDING LAYERS [BRAND, 1994]

Layer	Typical Lifespan/ activity
Site	Permanent
Structure	30-300 years
Skin	20+ years
Services	7-20 years
Space plan	3 years
Stuff	Under 3 years
Souls	Daily

TABEL 2: BUILDING LAYERS AND TYPICAL LIFESPAN [BRAND, 1994]

Duffy [1990] also believe a building to be modeled according to the technical and functional lifespan of building components. By modeling a building according to the life expectancy of building components, Duffy establishes four different categories within the building, also referred to as layers. The four layers described by Duffy are: Shell, Services, Scenery, and Set, respectively from longest life expectancy to shortest. Brand increases the number of layers with two, making a total of six layers. Adaptable Futures [2015] adds two more layers to the model of Brand: Surroundings and Social. (See Figure 17)

Habraken [1961] suggests a different building model, he proposes a building can be divided into support and infill, based on control and life expectancy, the "Open Building". Support is the collective domain of the building, and is seen as permanent. Building products that can be assigned to the support are the construction, the roof and the facade of the building. These building products have a long lifetime. The infill is seen as the individual domain, and is changeable. Building products that can be assigned to the infill are for example interior walls and furniture. These have a relative short lifetime [Habraken, 1961]. Habraken [1961] makes a division between permanent and changeable. Insterestig hereby is that Habraken emphasizes the division between the collective and individual domains. Decisions regarding the support domain of a building are made by for example the building community, the municipality or the building corporation, while decision about the infill are made by the owners or users themselves. However the complexity of building products as individual is not mentioned.

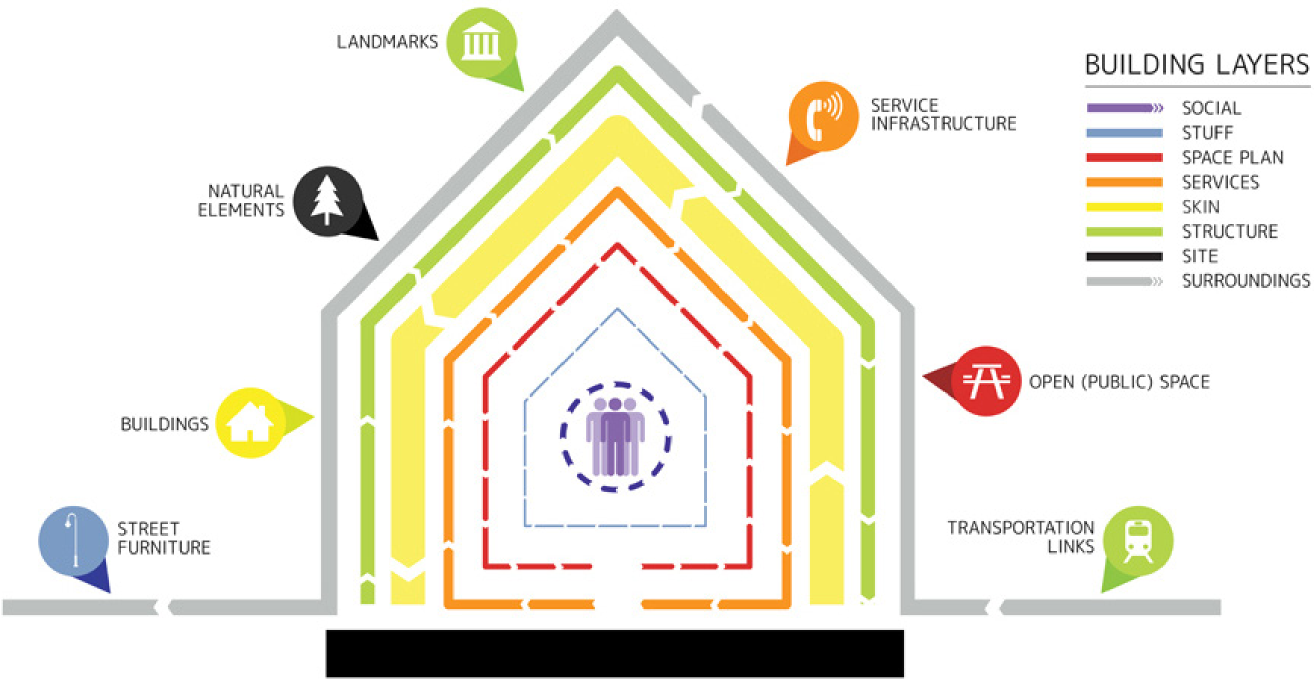


FIGURE 17: BUILDING LAYERS [ADAPTABLE FUTURES, 2015]

Another view from Durmisevic and Brouwer [2001] is to choose to see a building as a hierarchical collection of systems, components and elements. The highest level, being the building, is seen as a total collection of systems. The next level, the system, is seen as composition of components, which individually are in turn collections of elements and materials.

The division is made from the perspective of adaptivity, disassembly and reuse of the building. Durmisevic en Brouwer [2001] means the success of building decomposition will depend on level of decomposition of all structures within one building. The total amount of disassembly depends on the possibility of disassembly of all the layers in the hierarchical division.

While disassembly of a building focusses on the disconnecting different systems, disassembly of a single system is seen as dividing different components. The possibility of disassembling a single component depends on the amount of separable elements and materials. When every system in a building can be disconnected, and consists of different demountable components, it means every component within the system is replaceable. The same can be said for lower levels. When every component is replaceable, and it consists of only separable elements and materials, every element and material can be reused.

Durmisevic and Brouwer [2001] focus on adaptivity, disassembly and reuse when making the building model. They use a hierarchical division in a buildingdivision of a system to an element to the structural domain. Within this domain, different aggregation levels can be described: systems, components and elements, all separable from eachother. (See Figure 18)

Figure 19 shows the three main ideas next to eachother.

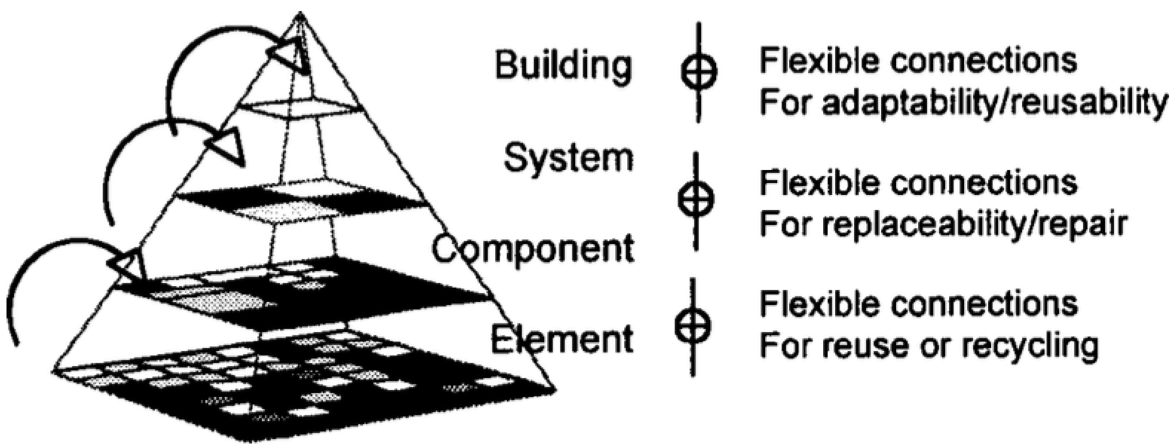


FIGURE 18: HIERARCHICAL COMPOSITION OF THE BUILDING, HIERARCHY OF SUBASSEMBLIES [DURMISEVIC & BROUWER, 2001]

FIGURE 19: COMPOSITION OF A BUILDING BY HABRAKEN, DURMISEVIC & BROUWER AND BRAND & ADAPTABLE FUTURES

2.3.3 DISASSEMBLY

Now that we know that a building consists of different parts it important to know how to disassmble those parts. Figure 20 shows the different levels of disassembling a building. The higher level more disassembly can be achieved

BUILDING TO UNIT

When the number of people decreases units can be removed or put down otherwise. Also, when the houses need to go to another location that is then possible.

UNIT TO COMPONENT

This phase focus on the replacing of broken components and rearranging of components to adapt to changing customer requirements. By enabling the disassembly of components they can be reassembled in new combinations. Alternatively, if they are no longer functional or desirable in the building itself, the components can have a second life somewhere else. Components having multiple lives can extend their functional lifetime to match their technical lifetime better. This results in components, and materials which they consist of being used in a more optimal manner.

If it is impossible to reuse the components as one, they can be disassembled into smaller elements. If connections of components are designed for this purpose, disassembly can be highly simplified. [Van Nederveen & Gielingh, 2009]

COMPONENT TO ELEMENT

There are components that are no longer useful for a building but that may be applicable to be reinstalled on another building. If components cannot be reused as a whole, it is possible that they can be disassembled into smaller elements which are than re-manufactured into new components.

The technology to re-manufacture used parts is already well- developed in the automotive industry. This saves on materials and avoiding of waste. If components that are not suited for remanufacturing, the materials from which they are made may be suited for recycling. [Van Nederveen & Gielingh, 2009]

ELEMENT TO MATERIAL

Design for disassembly, in this way, can serve as a material source for new buildings elements. Instead of extracting natural resources from the earth, the existing buildings are used a primary material source.

To make demountable buildings there are ten key principles of design for disassembly [Guy & Ciarimboli, 2005]:

“1. Document materials and methods for deconstruction: As-built drawings, labeling of connections and materials, and a “deconstruction plan” in the specifications all contribute to efficient disassembly and deconstruction.

2. Select materials using the precautionary principle: Materials that are chosen with consideration for future impacts and that have high quality will retain value and/ or be more feasible for reuse and recycling.

3. Design connections that are accessible: Visually, physically, and ergonomically accessible connections will increase efficiency and avoid requirements for expensive equipment or extensive environmental health and safety protections for workers.

4. Minimize or eliminate chemical connections: Binders, sealer’s and glues on, or in materials, make them difficult to separate and recycle, and increase the potential for negative human and ecological health impacts from their use.

5. Use bolted, screwed and nailed connections: Using standard and limited palettes of connectors will decrease tool needs, and time and effort to switch between them.

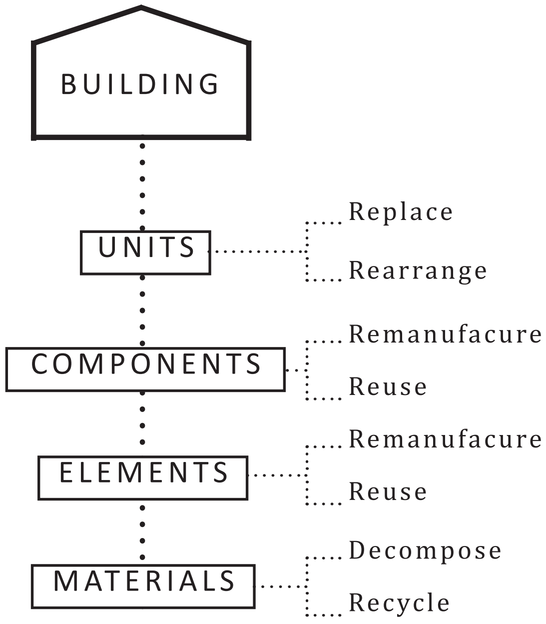


FIGURE 20: LEVELS OF DISASSEMBLING A BUILDING

6. Separate mechanical, electrical and plumbing (MEP) systems: Disentangling MEP systems from the assemblies that host them makes it easier to separate components and materials for repair, replacement, reuse and recycling.

7. Design to the worker and labor of separation: Human-scale components or conversely attuning to ease of removal by standard mechanical equipment will decrease labor intensity and increase the ability to incorporate a variety of skill levels.

8. Simplicity of structure and form: Simple open- span structural systems, simple forms, and standard dimensional grids will allow for ease of construction and deconstruction in increments.

9. Interchangeability: Using materials and systems that exhibit principles of modularity, independence, and standardization will facilitate reuse.

10. Safe deconstruction: Allowing for movement and safety of workers, equipment and site access, and ease of materials flow will make renovation and disassembly more economical and reduce risk.”

2.3.4 MATERIALS

A technical product is usually made of one or several materials and the sustainability of those materials needs to be considered through the entire life cycle [Ljungberg, 2005]. There are also several materials that emerge as a priority when dealing with circularity in the scoping study of the European commission (See Appendix B).

Selection of material is traditionally made by technical demands like price, strength of material, temperature stability, hardness, etc. (Brechet Y et al, 2001 & Mangonon 1999) However, for a successful sustainable product development, factors like reputation, fashion, product, cultural aspects, etc. must also be taken into account [Ljungberg, 2005].

An article on the Circular Economy Toolkit suggests that optimisation of materials can include:

1. Replacement of Technical for Biological materials,
2. Use of recycled material,
3. Removal of toxic materials
4. Eco-efficient materials
5. Reduction of scarce materials

2.3.5 CONCLUSION

The demolition decision is an important indicator of life-time homes. The life-time of social housing depends on the three factors: technical lifespan. functional lifespan, economic lifespan. Other reasons for demolition are oversupply of property type and urban planning. However different building layers have also different lifespan.

It is important to take into account during the production of houses the different building layers according to diverging lifespan of components.

To create circularity it depends on taking the disassembly possibilities into consideration when designing building products. This can be done by making connections dry and logical.

2.4 Design considerations

Taking into account the technical considerations we are able to make logical design decisions. From the previous chapter we now know that a house should be able to adapt and be flexible for future changes. However, conventional houses are not designed to adapt to the changing demands of the next user. This chapter shows some of the design aspects involved into the creation of flexible or adaptable building.

A transformable system has impact on the social, environmental and economic systems. It is now clear that every building has a negative impact on the environment when it's built and demolished. Transformable houses should be designed for reuse, reconfiguration and recycling. The quality of a building in the future will be measured by the flexibility of structures and their environmental efficiency. [Durmisevic, 2006]

2.4.1 THE DESIGN OF A HOUSE

The built environment consists of buildings. According to Prins [1992] a building is physically considered to be a set of parts that can change over time. A building could also be considered to be a storage depot for raw materials.[Rau, 2015] Although there is no consensus as to what a building consists of, there is no contradiction between those statements, the two definitions can coexist. It depends on the perspective if a building a product is, a group of components, or a collection of materials. Designing a flexible building is about how we arrange the composition of a building.

The original main function of houses is to provide shelter. Today, by innovation, automation and new technologies are building companies focusing on making products and industrializing the processes creating a house like a product. The standardization of a product can facilitate a CE. But because this product is part of the building environment we need to be able to customize it. So, not only mass production is important also mass customization is important. By producing in mass production we are able to make it affordable and with a high quality and with mass customization we are able to keep the aesthetically value of the built environment.

During the years there have been a lot of attempts of making a home like a product. Houses were than built by mass production to decrease the housing shortage. One example is the Jean Prove with the 6x6 demountable house. He was one of the founders in prefabrication in the building industry. Jean Prouvé won an order for emergency housing from the Ministry of Reconstruction and Town Planning. First built in 1944 to rehouse war victims in Lorraine. Readily transported and dismantled the components were shipped directly to bomb-devastated villages, where they could be assembled on site in a day by two people, enabling the homeless to stay on. Unfortunately, the shortage of materials and funding together with official emphasis on the need for permanent housing meant that production of these transitional dwellings never passed beyond the limited series stage. [Neumann, 2004] The ideas of Prouvé were fits the principles for a CE. All of his buildings were based on a standard dimension of one meter. And everything was very easy to disassemble. [Neumann, 2004] Jean Prouvé looked a lot into industrialized production process like of cars. Where the production is very clean and streamlined.

In a car you are able to take every part apart and replace it when necessary. You can keep the chassis and use to make a new car. With a house that is a different case, the base building or structure or the chassis of the house and what is inside (the fit out) is now being viewed as a whole from the legislator, however they have a totally different life span. But they are also not easy to disassemble. This makes it difficult for the building industry to change to circular process.

2.4.2 DESIGN CHALLENGES

There are in my opinion four main challenges in designing a production process that enables a circular process: dimensions, connections, lifetime of components and standardization of components.

DIMENSIONS

A beneficial recognized measure in the context of social housing is 6x10 meters. [VROM, 2004] Realizing this measurement every function of a house can be done in one level. One module is then suitable as a starter home. However the dimensions of the structure or casco is mainly determined by the land division.

To create a circular process it depends on the dimensions,s by taking into account of modular coordination in creating a standardization in the building process.

CONNECTIONS

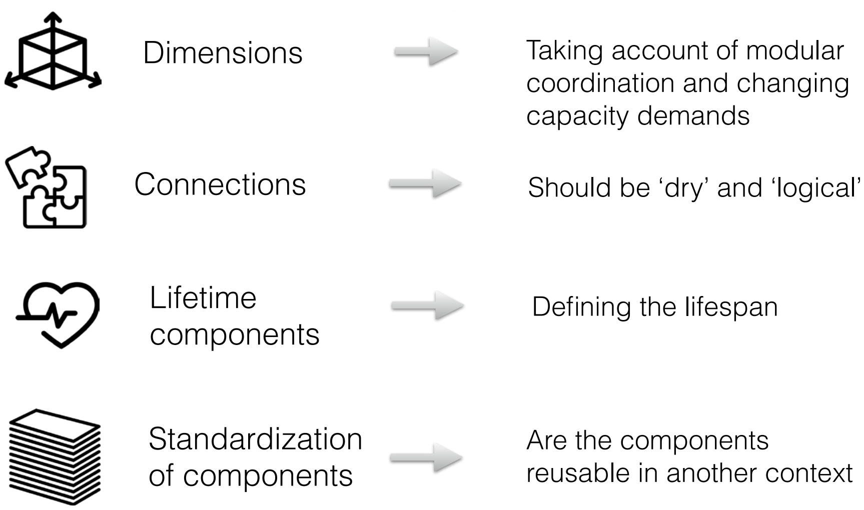
As discussed in the last chapter it is important to be able to disassemble a building to create circularity. The design the connections is hereby important. The connections between elements and components should be designed in a dry a logical way.

LIFETIME OF COMPONENTS

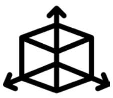
Taking into account the lifespan of components in the design is important because of the different lifespan of different components. By separating components with different lifetime it is then easier in the future to change those with a shorter lifetime.

STANDARDIZATION OF COMPONENTS

According to Geldermans and Jacobson [2015] a certain level of standardization is inevitable to create circularity in the building process. It ensures that materials and products can be reused in multiple buildings or systems without significant adjustments. Standardization of connections is found to be key in this respect, particularly (dry) connections in the fit out domain. [Geldermans et al., 2015] The challenge hereby is to keep the diversity in the built environment and the architectural freedom in the design when applying in a big scale.



Per building layer we are able to asses these different design challenges and improve the design. By doing that the overall process will be more circular. Tabel 3 shows the different layers combine with thedesign challenges. Each layer differs where certain changes needs to be done.

Assessment per Layer				
Structure	• Dimensioning facade grid • Modular coordination	• Connections of foundation • Connections between elements	• Thermal and acoustic quality of floor insulation • Fire resistance	• Geometry of columns and beams • Shape of floor-plan
Skin	• Dimensioning elements	• Dismountable elements	• Insulation components • Daylight entry • Reuse windows	• Size of elements
Services	• Dimensioning shafts	• Dismountable installations components	• Capacity of installations • Facilities	• Possibility to upgrade components
Space plan	• Dimensioning Partition walls	• Connections partition walls, stair and doors	• Reuse of stair and interior walls	• Size of components • Individual finishing

TABEL 3: BUILDING LAYERS AND DESIGN CHALLENGES

2.4.3 ADAPTABLE DESIGN

Adaptable Futures at Loughborough University (UK) has done a lot of research on the matter of what it means to make an adaptable design.

To make a design adaptable is important to take into account the changes that happens over the years. Short term alterations within five years are suppose to react to the changing trends or norms and are often aesthetic. After 5 years, also more physical changes in a house are needed. Maybe the relocation of inner walls to create new spaces, an upgrade of the installations, or new window frames.

The structural layer of a social house will probably never need to change, this depends on the choosen dimesions of the design beforehand. The adaptability of a house is critical to the flexibility possibilities in the long term. The more adaptable a house is, the longer the functional life-time can be.

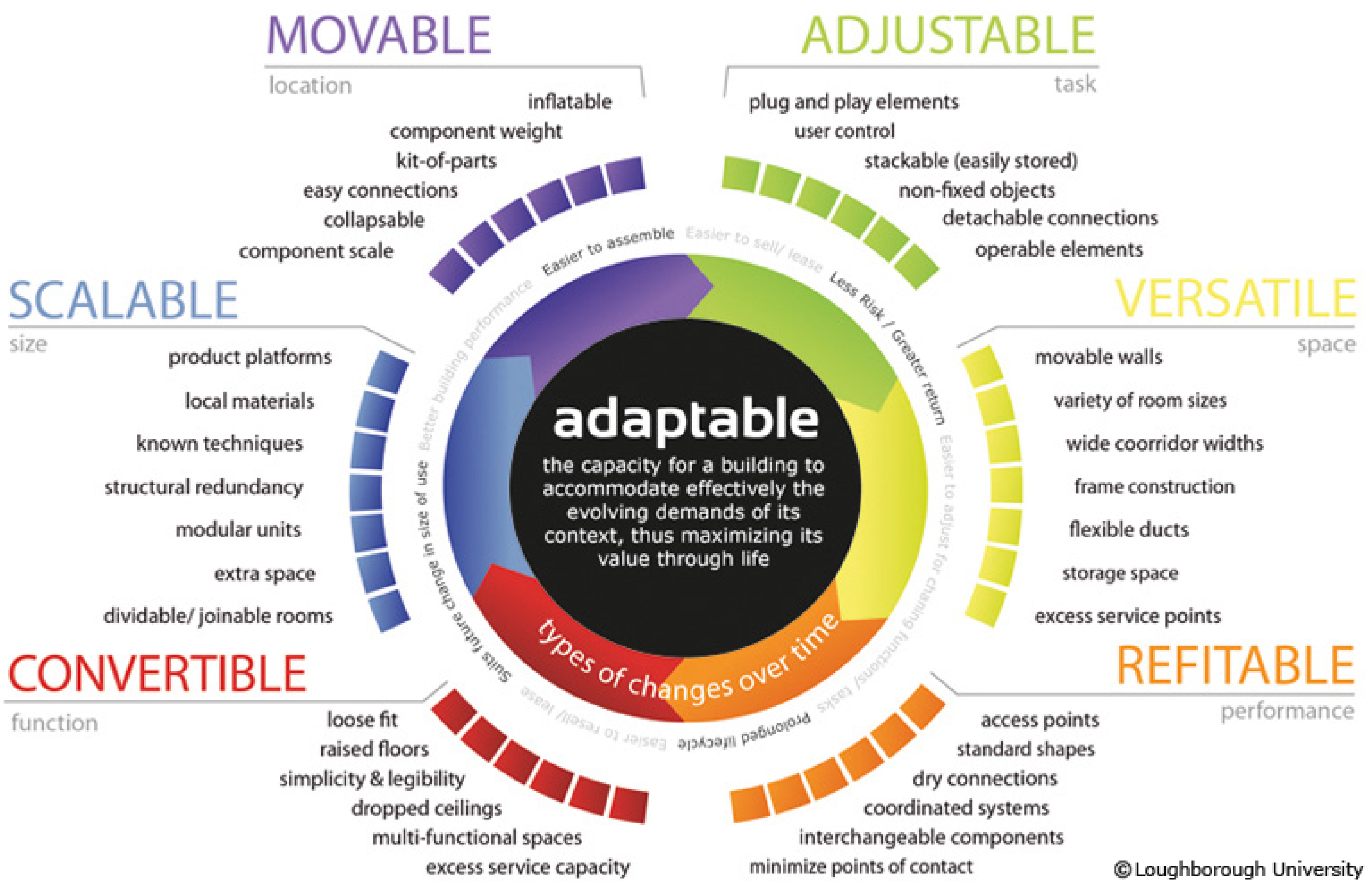


FIGURE 21: ADAPTABLE BUILDING [ADAPTABLE FUTURES, 2015]

2.4.4 CONCLUSION

During the design of a house it is important to take into account strategies for disassembly and make sure to incorporate future reuse. Components need to be designed in a way that they can be replaced, this way a house can be mantained and updated. At the end of the life-time of the complete house the components can be disassembled and reused in new projects.

To be able to achive that circular process a certain level of standardization is needed. However standardization may limit the architectural freedom. But by standardizing components it is possible to build a lot of high quality housing in a fast way and for a low cost. On the other hand the freedom in design will become lower due to the limited possibilities of different components available of the building system.

2.5 FINANCIAL CONSIDERATIONS

By making technical and design changes we are able to change the linear process into a more circular process. But those changes come with a price. In the building industry financial choices play a very important role in decision making. This chapter describes from a financial point of view some of the considerations on aspects that need to be taken into account by changing the traditional process to a more circular process.

2.5.1 CURRENT LINEAR TRANSACTION

In today's economy the most common method of transactions happens in a linear way, a linear transaction. This represents a one-way sale transaction of a product between a supplier and a client. This is also the case for a construction company like TW. TW buys building products from different suppliers and makes a new product, houses, and sells these houses as product in a one way transaction.

In our current economic model taxation on labor is relatively expensive compared to materials, that have barely any additional charge. What then happens is that companies economize on the use of working people and not on primary resource consumption. It would be good to create an incentive to support labor intensive reuse.

The separation of the different building layers may provide us with new, beneficial economic, legal and tax possibilities. Building products with different life-time may have different business models.

2.5.2 PRODUCT AS A SERVICE AND SALE & BUYBACK

Instead of using the traditional linear transaction of selling products, it's possible to offer a product as a service. The product is taken by the customer and they pay for the time or usage of it, for either a short or long contract period. The provider typically has ownership of the product throughout the entire life-cycle and can manage the product through design, usage, maintenance, reuse, re-manufacture and recycling.

This business model allow closer relations with the customer, enhanced product development for closer feedback loops, provide greater business value to both parties and improve customer satisfaction. Although this may sounds promising there are a lot of risks and obstacles involved. Major up-front investment costs are need when a company provides a product as a service. [Kok et al.] Another obstacle are environmental costs (externalities) that are not taken into account. [Kok et al.] Recycled materials are often still more expensive than virgin [Kok et al.] and there are higher costs for management and planning. [Kok et al.] There is also the risk for a supply company when building products are not in demand, making the company store the product, loose possible revenues, and deal with the qualitative decrease of the product over time.

A linear transaction leads to the moment where the contact between the client and the construction company can be lost. With a sale and buyback transaction the contact with the client can be preserved. The construction company and the client may choose to stay in contact during the use phase, this way they can stay updated about the state of the building. At the end of the use cycle the construction company will perform an inspection to determine the condition of the building and may buy it back. With a sale and buyback transaction, ownership of the building transfers from the construction company to the client.

With lease, ownership of the building is retained by the construction company. In both scenarios the client does not have freedom in making any changes to the building, this need to be made in collaboration with the construction company.

2.5.3 VALUE OF REAL ESTATE

Property is besides shares and bonds, the third main investment category for pension funds, insurance companies, banks and wealthy families. The location provides in combination with the function of the building - living, working, recreation etc. - the price per square meter. Each residential function has on the basis of rental income or the image of the location a certain yield range per m2.

The CE is based on adding value on long-term and not to achieve rapid return on separate transactions. However this is now the current situation. So the question is how the different actors can add value for the long term and how they can be rewarded for this value addition.

For an investor the value of the location and value of the building together determine whether the investment is profitable in the long run. It is therefore logical that the investor fully is focused on a flexible basis with building a good foundation, structure, facade and roof. Responsibility for short-term investments for the built-in like the kitchen, bathroom goes to the end user.
Retrieving the building product is connected with the residual value of the product. This value depends on the market, making the total residual value of a product to be seen as the market value.

The market value is composed from the resource value, the component value and the function value. Furthermore, the cycle value has a certain influence on the market value.

2.5.4 CURRENT FINANCIAL MODEL TW

The current model of TW is based on a linear transaction where TW the houses sells to a client. In this case the houses are sold to a housing association.
The business model is simple the more houses are sold the more profit TW will make. So by making the houses fast while keep the quality the more houses are sold.

Housing associations have a fix amout that they can pay for houses. So how cheaper TW produces the houses, the more profits they can make.

2.5.5 CONCLUSION

For the current business model of TW it is difficult to relate to a timespan of 50 to 100 years. Time perspective is now related to a timespan of 7 to 10 years. Time perspective is very important. It is for companies very difficult to relate to a timespan of 50 to 100 years. The most can only relate to a time of 7 to 10 years. It is therefore difficult to compromise with a choice related to a long-term advantage.

The main consequence for improving the design and technical aspects to facilitate circularity will be financial. Due to the changes the components will be relatively more expensive. The houses will therefore be more expensive to produce. To change the process into a circular process some changes financial sector is needed, seeing the value of the new business models and being prepared to invest plays an important role.

Increasing resource prices is also important for the transition to circular. The prediction of resource scarcity in combination with a growing world population would result in an increase in resource prices, making product reuse more attractive.

Using the model product as a services improves the relation between clients and contractor throughout the entire life cycle of the building.

2.6 Facilitating circularity

With the separation of the diferent layers of a building we achieve truly sustainable building.
In a modern building we mix or glue no materials and we certainly do not put installation systems in concrete. All parts are separately replaceable when their life cycle is complete. We move from consuming to using and reusing. We regain valuable (biological) materials where we can.

To facilitate circularity the knowledge of the building is very important. By knowing exactly what a building consists of, is possible to get rid of harmful substances. It is important that you can disassemble the building, the different components and materials. Separating the building in layers makes that more accessible. Making changes to make it more disassemble has direct effect on the cost. So it is important to know if it is feasible to make those changes and if not maybe by changing the business model this could be possible.

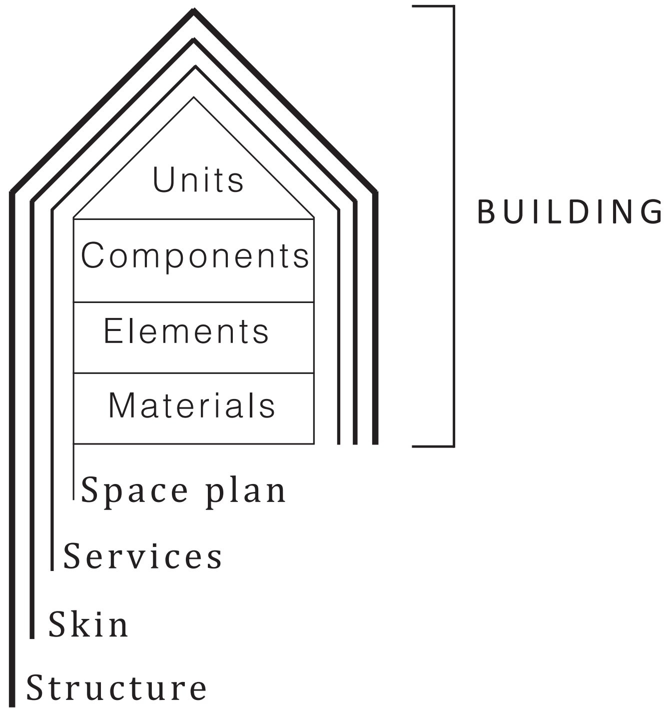


FIGURE 22: LAYERS AND LEVELS OF DISASSEMBLY

PRODUCTION
- MINIMIZE WASTE PRODUCTION
- MAXIMIZE EFFICIENCY
- MINIMIZE PRODUCTION TIME
- MINIMIZE HUMAN LABOR
- MINIMIZE ONSITE ACTIVITIES

ASSEMBLY
- DRY ASSEMBLY
- EASY TO DEMOUNT
- NUMBER OF COMPONENTS

MATERIAL
- USE OF RECYCLABLE OR REUSABLE MATERIAL
- AVOID HARMFUL SUBSTANCES, MATERIALS
- TAKE INTO ACCOUNT MATERIALS IN RELATION TO LIFETIME AND REUSE

DESIGN
- FREEDOM OF DESIGN IN LEVEL OF FINISHING
- CONSIDER PRODUCTION PROCESS
- DEVOLOPMENT OF STANDARTIZATION

USE
- MAXIMIZE ADAPTABILITY
- MINIMIZE MAINTENANCE

FINANCE
- MINIMIZE EXTRA COSTS
- CACULATE COSTS IN COMBINATION TO LIFESPAN AND REUSE
- USE OF PSS, BUY BACK

3. CASE STUDY

3.1 TW, project Barneveld

The basis of the TW building system is formed by a steel chassis. The solid floors are concrete. The construction is therefore very strong, stable and dimensionally stable.

The exterior walls are mostly made of brick but also other materials are possible. The partition walls have high sound and heat insulation. The walls are vapor open. These features makes living comfortable.

The homes are built per floor. The dimensions of the units are flexible. Also, the dimensions of the floors are free to determine, both in width, depth and height. Even each individual property of a row can be chosen freely in size, number of floors, architecture, layout, finishing and installation.

The architecture is flexible. TW collaborates with different architects, each with its own style. The client may also bring his own architect.

The layout of the building elements is flexible. Obviously there are various options for organizing the living room, kitchen, bathroom, bedrooms, stairs and partitions. TW share knowledge and experience with regard to creating a comfortable living space. TW provides different models of bathrooms and toilets with different options and accessories. TW modular system makes it possible to build a high-quality prefab bathroom. The kitchen can be directly built this way the house can be occupied immediately after completion. TW homes can be delivered fully finished and ready to move. Interior and exterior doors and frames are in various styles and sizes. And the walls can already be delivered in desired colors and desired finish.

This case study is based on a project in Barneveld that is completed in June of this year. The project is for residence permit holders.

FIGURE 23: INSTALLATION OF A HOUSE [TW, 2016]

3.1.1 LOCATION PROJECT

On temporary license 22 housing units on a temporary basis. The destination is 10 years for housing available then they should be moved. The houses have a minimum life of 50 years.
The site is located in a small town called Barneveld. The location was the sport field of a elementary school.

There are three types of dwellings in this project. Type S, Type M and Type L. Every type can also be made in a variety of sizes.

FIGURE 24: LOCATION PROJECT [THINK WONEN, 2016]

3.1.2 CURRENT PRODUCTION PROCESS

The current production process of TW is still linear. First suppliers of elements harvest the materials to produce the elements. After the design phase TW buys the elements and some components and put the elements and components together into units.

After the placement of the units and the work on-site the building is finished. By reorganizing the way TW produces houses it could be possible to transition to circular process.

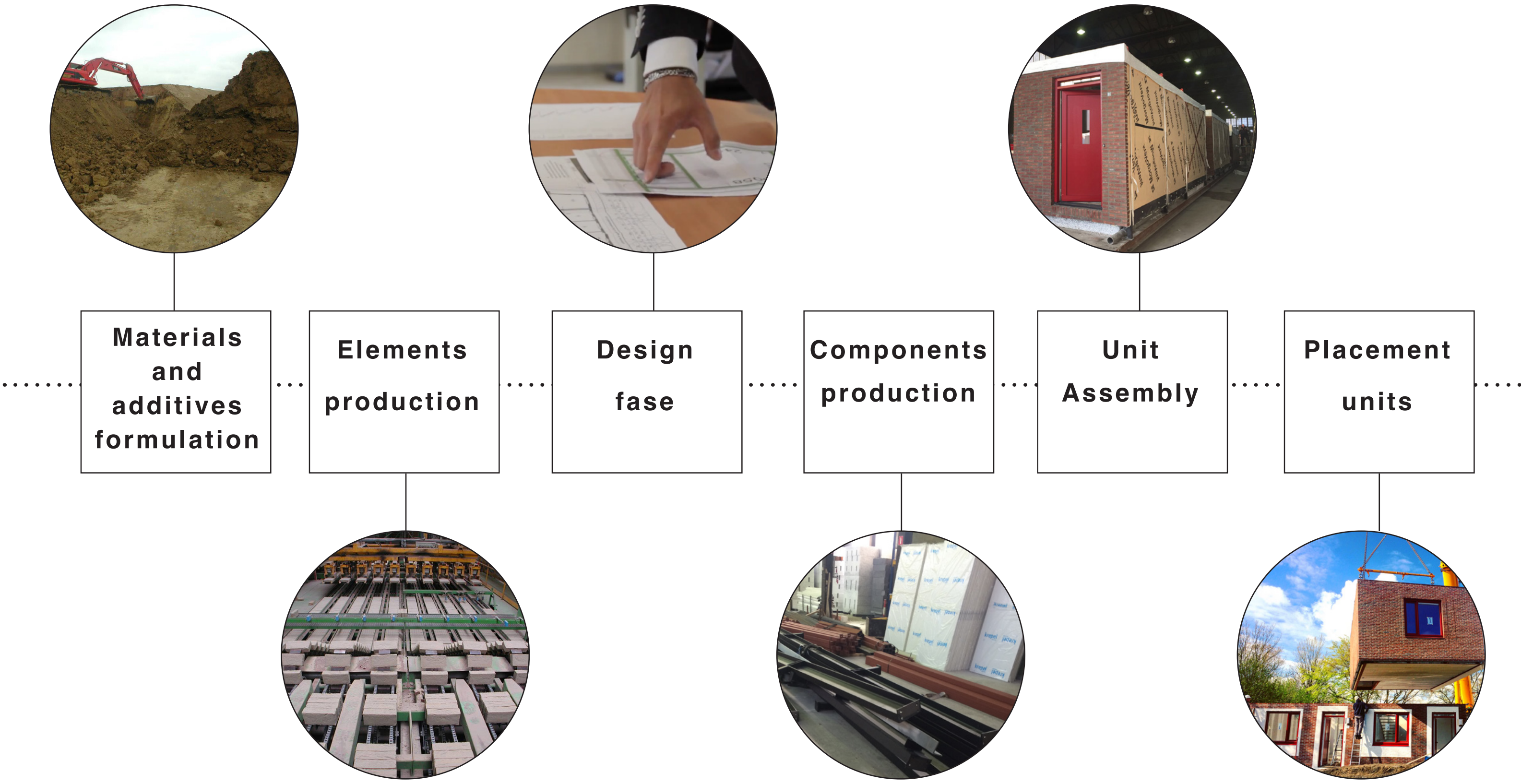


FIGURE 25: LINEAR PRODUCTION PROCESS

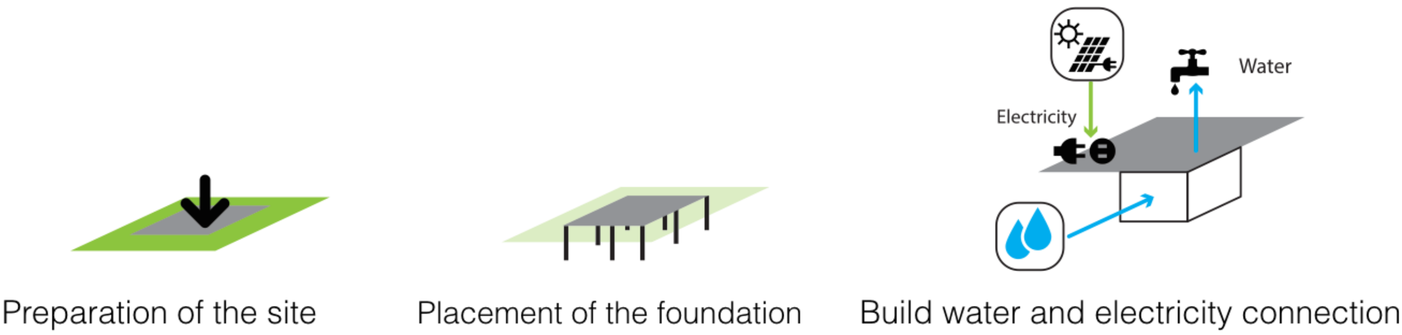
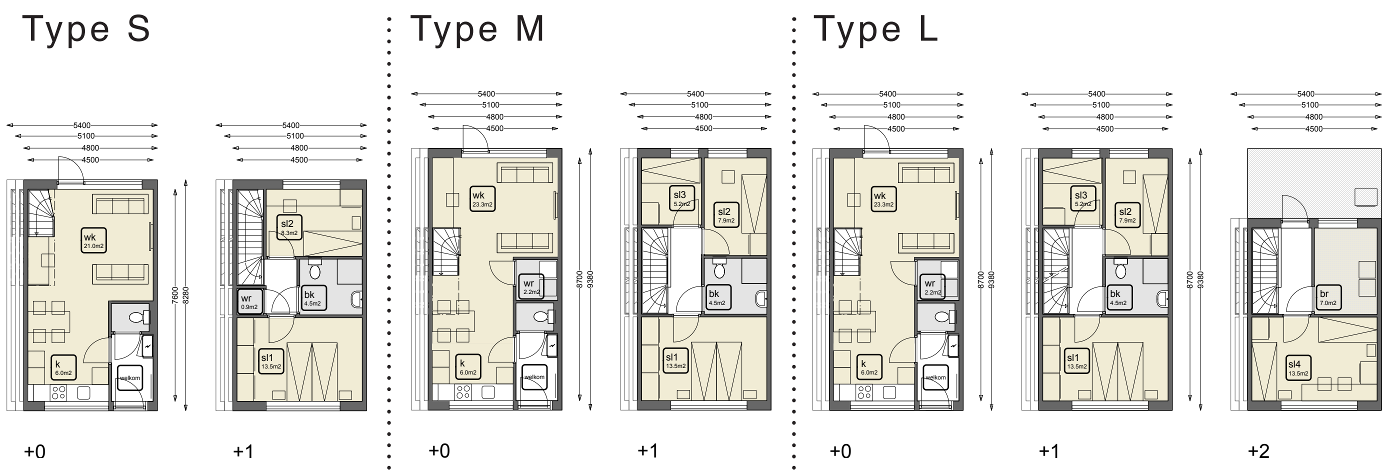


FIGURE 26: ACTIVITIES ON-SITE



Type S
4800mm x 8280mm
1 - 3 persons
79,5 m²

Type M
4800mm x 9380mm
3 - 4 persons
90,0 m²

Type L
4800mm x 9380mm
4 - 6 persons
123,1 m²

FIGURE 27: TYPE HOUSES [THINK WONEN, 2016]

3.2 UNIT ANALYSIS

If we combine the different building layers with the levels of disassembly we get a scheme as we can see in Figure 28. So a house consist of Units, components, elements and materials. And that is divided into four layers. Space plan, Services, Structure and Skin.

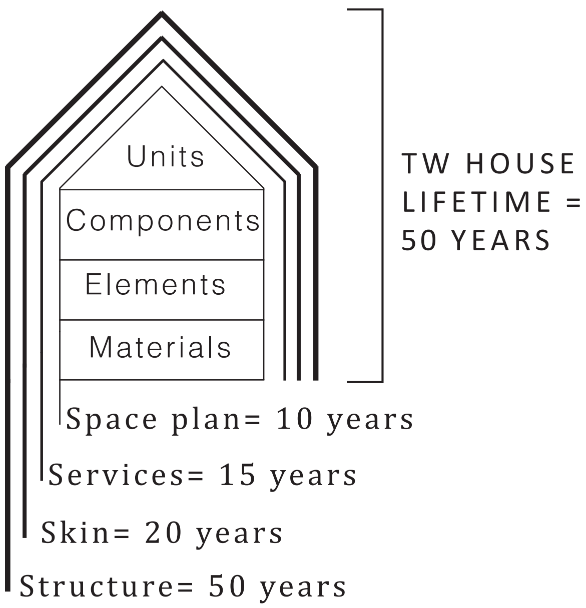


FIGURE 28: HOUSE LAYERS AND LEVELS OF DISASSEMBLY

According to TW a TW house has the lifetime of 50 years. In reality the lifetime of a house is much longer and each layer has a different lifetime.

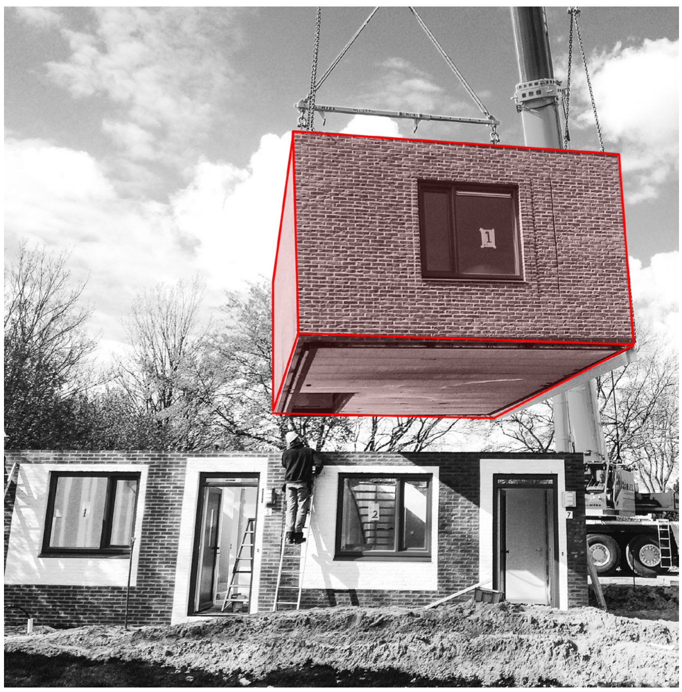
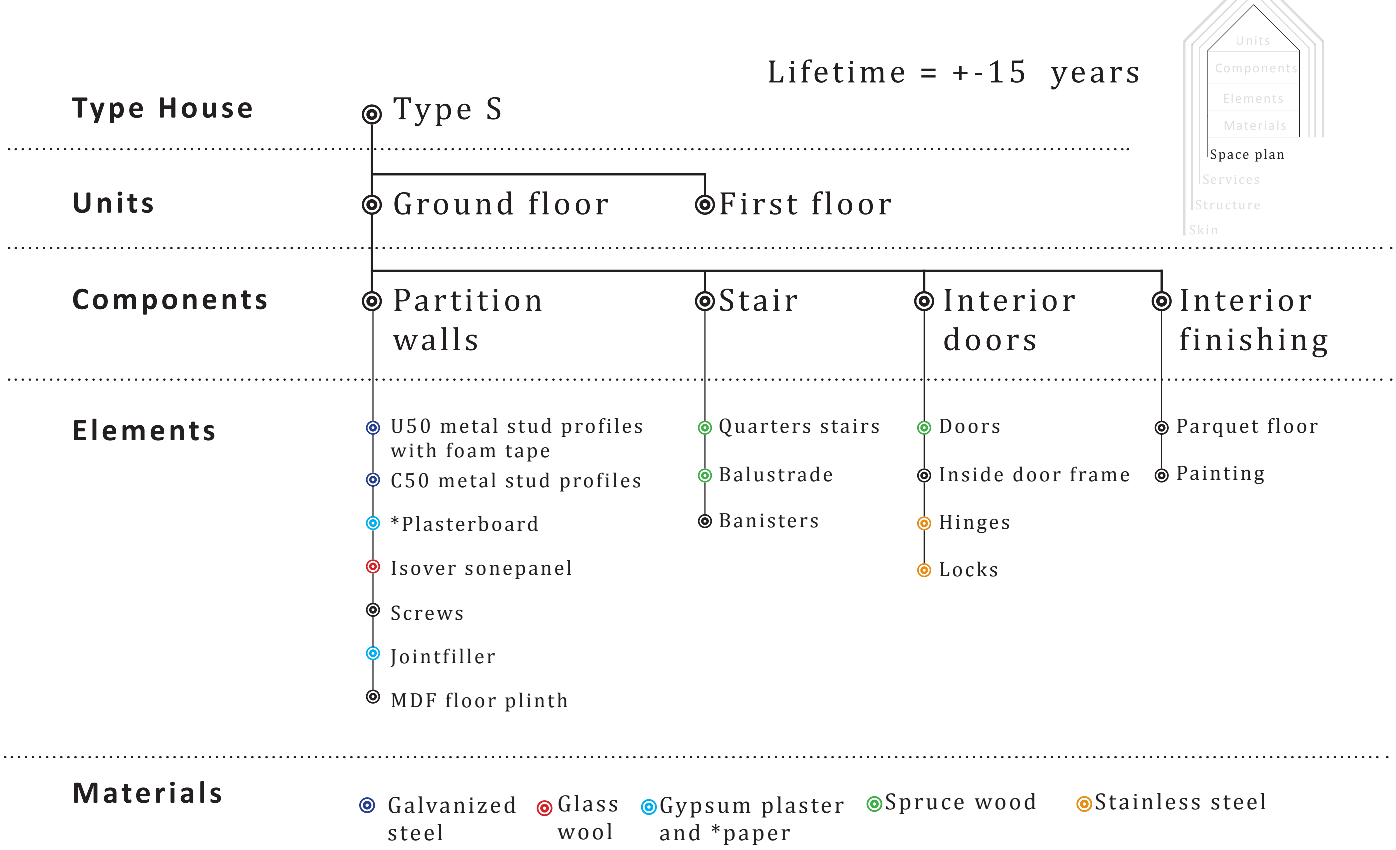


FIGURE 29: HOUSE UNIT

To disassemble a house first we need to know what are the units, components, elements and materials. We are going to access this per building layer.

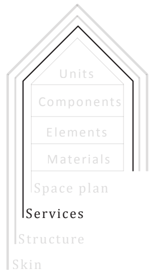
3.2.1 SPACE PLAN



The partition walls is a metal stud wall, witch galvanized steel profiles, plasterboard and glass wool. The stair is a quarters stair and it is of spruce wood. The interior doors is also of spruce wood. And there is the interior finishing. Connecting the partition walls and stair are bad connections and the reuse of the stair and interior walls is not possible. This has to do with the chemical connection that is used above the technical connection.

So we need to get rid of the plaster and joint filler. A better option for plasterboard is needed. This layer has a lifetime stated of around 15 year, however most of the components have the lifetime for a least 50 years. Also an alternative for glass wool is needed. This could be wood fiber or Hennep.

3.2.2 SERVICES



Lifetime = +-15 years

Type House
- Type S

Units
- Ground floor
- First floor

Components
- Prefab toilet
- Heating
- Kitchen
- Electrical
- Ventilation

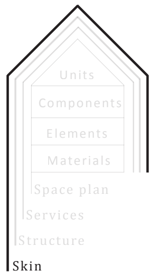
Elements
- Prefab toilet: Steel frame, Toilet bowl, Sink, Plaster wall, Tiles
- Heating: Hot water heater's container, Infra-red plates, Water pipes
- Kitchen: Electric stove (ceramic glass), Electric suction to roof, Kitchen plate, Sink, Wall cabinet, Cabinet, Kitchen drawers, Standard handles
- Electrical: Electric wires, Sockets, Meterkast
- Ventilation: ClimaRad

Materials
- Steel
- Stainless steel
- Copper

At the service layer we have the prefab toilet, heating, the kitchen, the electrical and ventilation. The prefab toilet is not possible to easily disassemble it and it has elements with different lifespan. And therefore it is not possible to upgrade it without creating waste.

FIGURE 30: PREFAB TOILET, HEATING, KITCHEN, ELECTRA AND VENTILATION

3.2.3 SKIN



Lifetime = +-20 years

Type House
- Type S

Units
- Ground floor
- First floor

Components
- Facade
- Separating wall
- Roof

Elements

Facade:
- Bricks
- Cement mortar
- Wall ties
- Murfor
- Window sill
- Window frames
- Water repellent vapor permeable layer

Separating wall:
- Woodframe
- Insulation
- *Plasterboard
- Lateislabbe met double profile 300mm
- Kit
- Window (double glass)

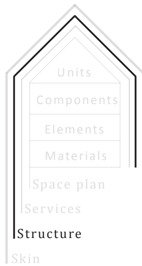
Roof:
- Roofing
- Sloped Insulation
- Vapor barrier
- Cellular concrete floor

Materials
- Galvanized steel
- uPVC
- Clay
- Glass wool
- Gypsum plaster and *paper
- Spruce wood
- MS-Polymeer
- Cement and sand

In the skin layer we have the front and back facade, the separating wall and the roof. Future reuse of this layer will probably not happen. This has to do with the size of the elements and the fact that the component are not connect in a dry way. An alternative for the traditional brick wall could be click-brick where cement mortar and murfor is not needed. The window frames are now made of PVC another option could be Aluminum.

FIGURE 31: FACADE OUTSIDE

STRUCTURE



Lifetime = +100 years

Type House: Type S

Units: Ground floor · First floor

Components: Structural frame (chassis) · Foundation · Floor

Elements:

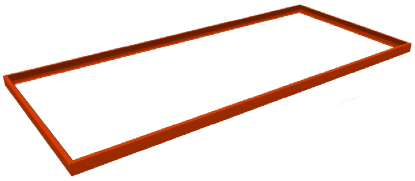
- Structural frame (chassis):
  - 14 x HEA 100
  - 13 x L 80x8
  - 6 x IPE 200
  - 4 x U240
  - 4 x SHS 80x80x5
  - 3 x L 100x10
  - 2 x SHS 80x80x3
  - Fl 60x6-S235JRG2
  - Nut M30-8.8
  - Nut M16-8.8
  - Plate 10, 12 and 20
- Foundation:
  - Top plates
  - Foundation piles
- Floor:
  - Cement top floor
  - Concrete floor
  - Insulation
  - Reinforcement net
  - Prefab pipelines

Materials: Steel · Stainless steel · Concrete c20/25 · PVC · EPS · Cement and sand

In the last layer we have the structural frame, foundation and floor. The structural frame could change some of the connections that are welded with bolts connections. In the concrete floor are plumbing, to make this layer more circular we need to separate those.

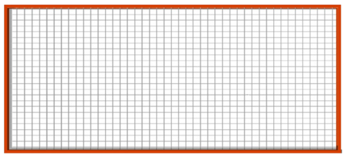
In the current situation the dimensions of the concrete floor varies a lot. In the images below you can see in more detail how the floor is made.

For TW the structure layer is the most important because it is the most expensive part of the building. However it also has the longest lifespan, making it difficult to create cycles.

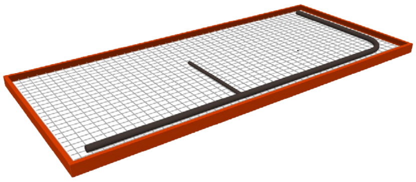


1. Steel base frame is mounted.

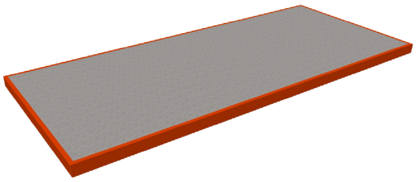
2. EPS insulation is placed.



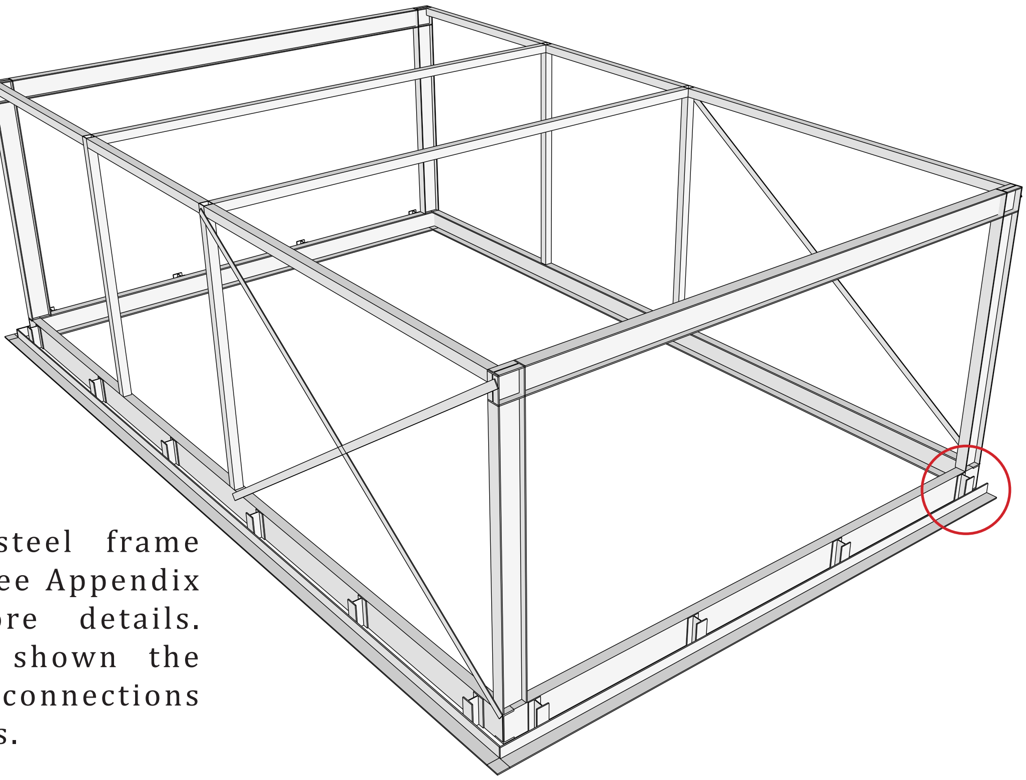
3. Steel reinforcement is placed into place.



4. PVC prefab pipelines is installed.



5. Concrete is poured



Complete steel frame mounted. See Appendix E for more details. In red is shown the welded connections that repeats.

3.3 Current production process

3.3.1 Production process

The production of the houses of TW happens in a production line. There are in total five stations in the production line.

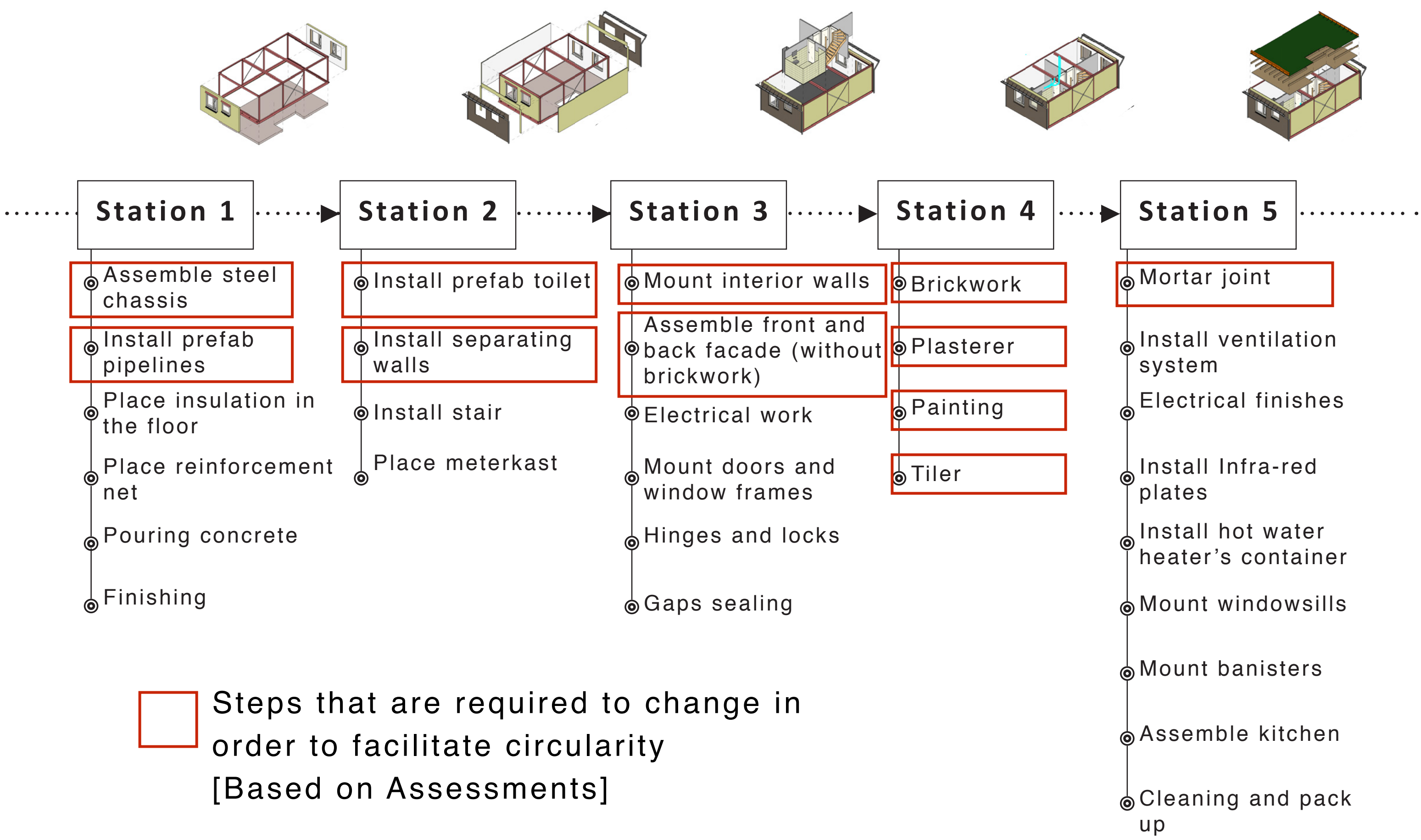
Station 1
This applies for both ground floor and levels floor. Floor is created. Reinforced concrete floors and insulated ground floor. Two wire mesh is required. Piping is installed in the floor before pouring the concrete. After pouring, it is no longer possible to get to the pipes.
At ground floor PS is placed underneath and then poured with concrete. Floor power floated.

Station 2
Prefabricated toilet and bathroom. Partitions are used. Trap is deployed and the electricity meter cupboard is installed.

Station 3
Doors and windows and rear are put down. Most of the electrical work is done.

Station 4
This station is reserved for the brick work. Also plasterer, tiling and painting is done in this station.

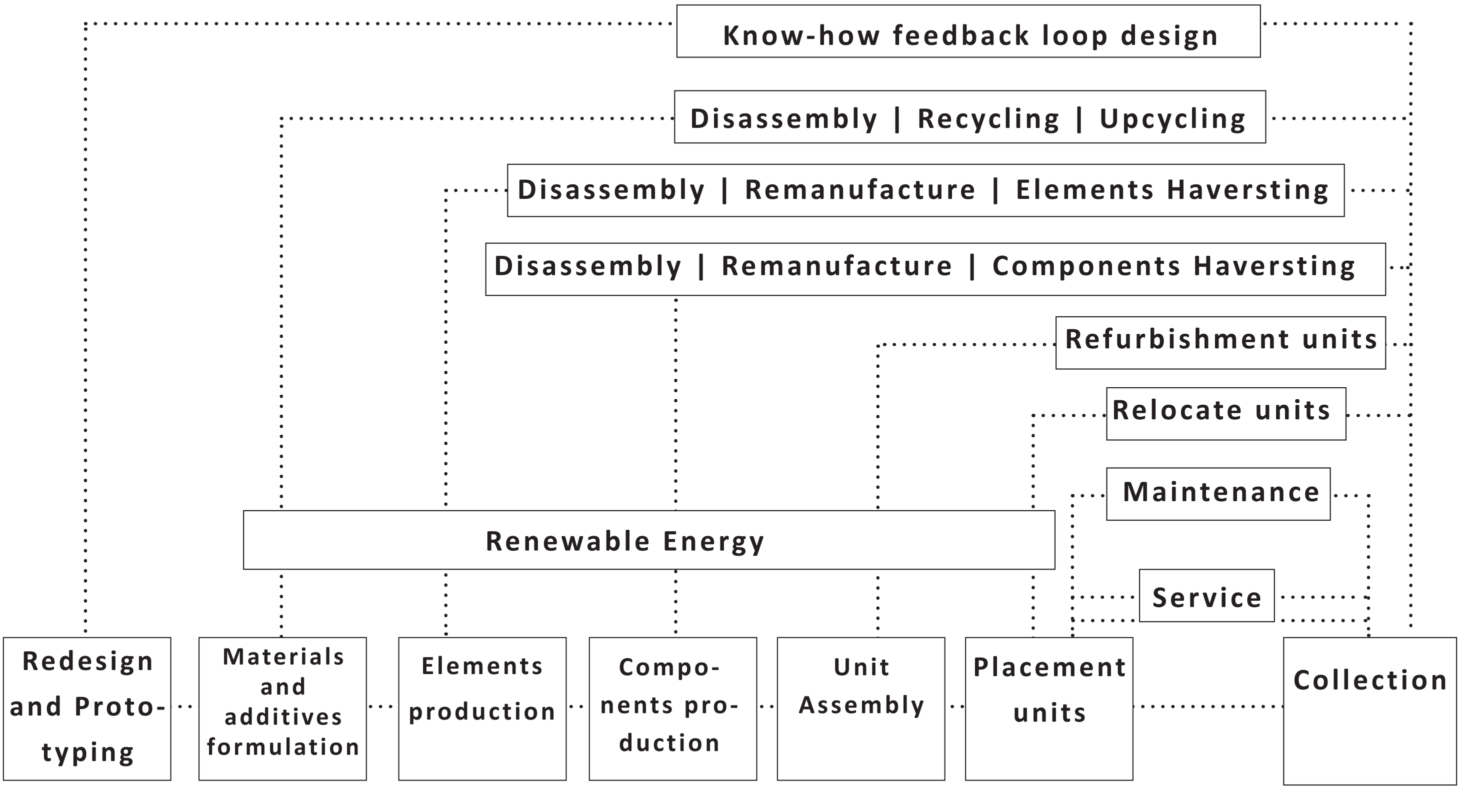
Station 5
All the finishing happens here. Also the installation of the remaining services and kitchen. The unit is then cleaned and packed with a plastic cover.



4. DESIGN PROPOSAL

4.1 THE NEW ORGANIZATION

In the current organization of social housing the Housing association owns the properties as a whole and they rent to the end user, (in this case the residence permit holder).



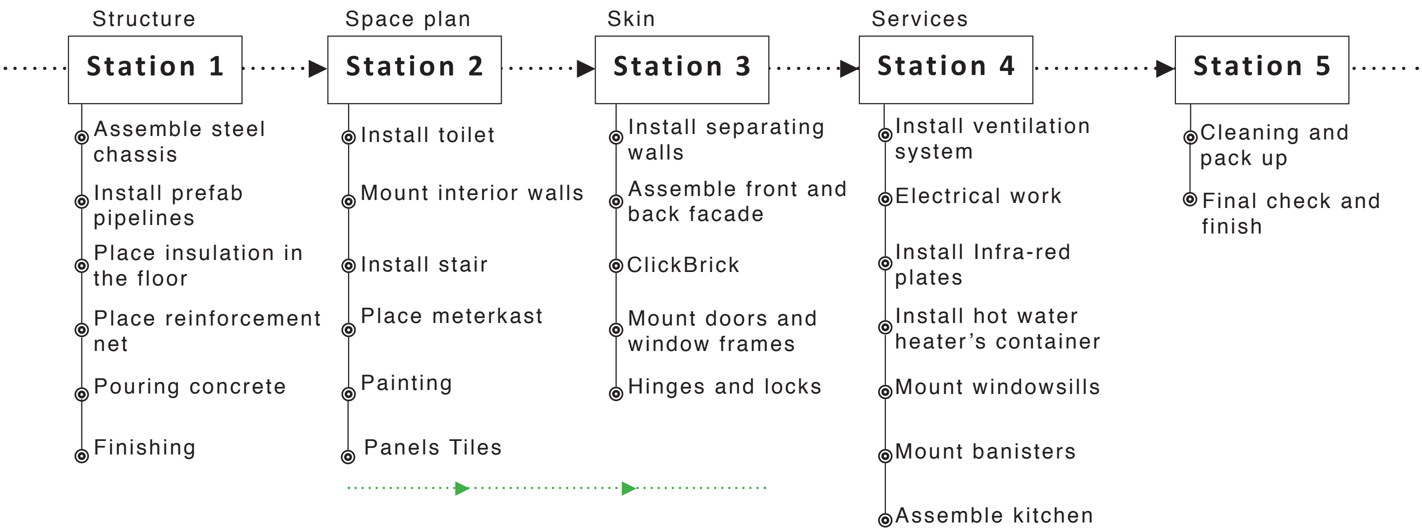
4.1.1 NEW ROL OF TW

The new role of the contractor in this case TW is to the design, construction, management and maintenance. Where for different layers of the house different business cases are able to appear. TW needs to know when to replace each component and reuse the components. This creates more administration work for TW and a better relation with the client.

Because TW manages the houses and TW is then able to see where the improvements are needed, thereby creating a better product every time. The user will also benefit from because the house will gets better every time.

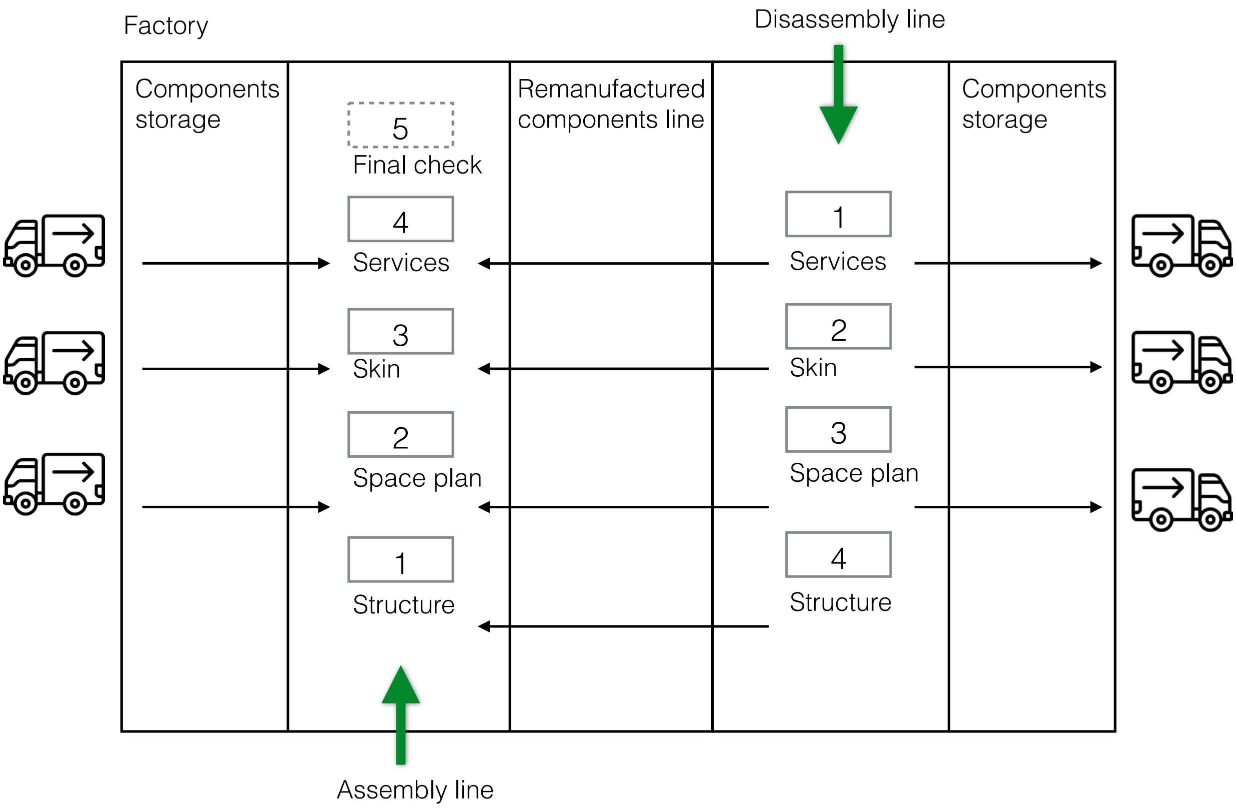
4.1.2 THE ASSEMBLY LINE

Separating the layers already during the production will facilitate circularty. Reorganizing this way obligates to really separate different components.



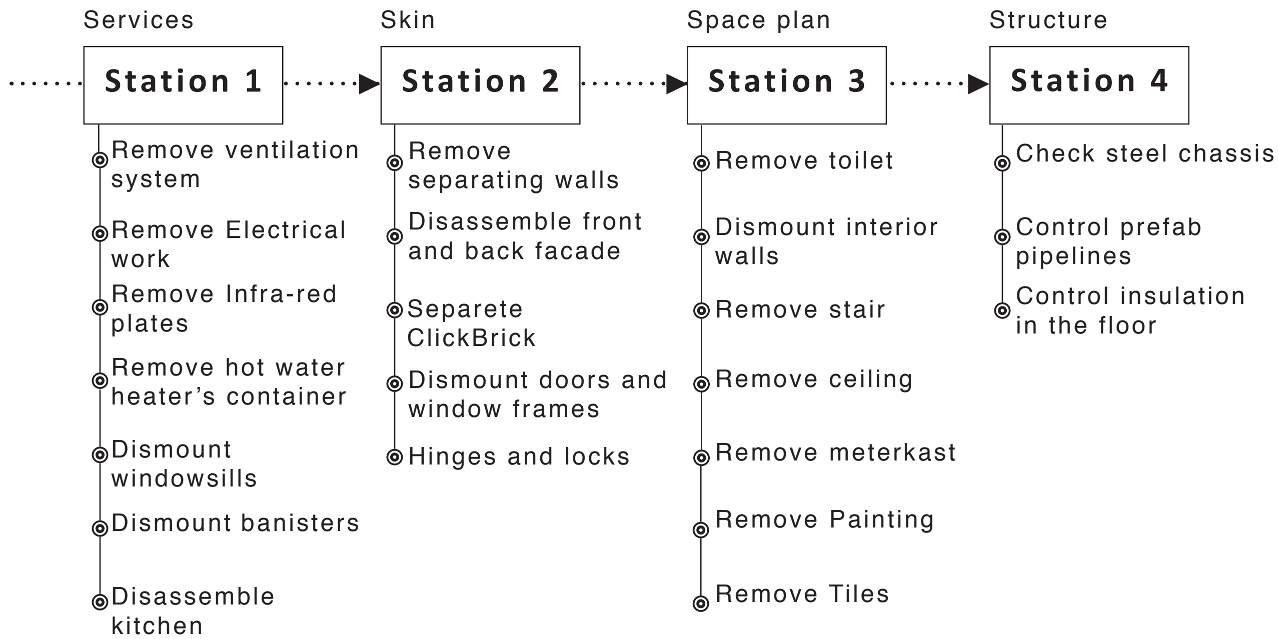
The ideal scenario would be if TW really was able to retain the units after for example 50 years. This may happen, however this is not a realistic scenario. As seen in previous chapters different layers have different lifespan.

And that also differs per component. The lifespan of a house is also almost never 50 years. An essential aspect of circular building is the return logistics. Reusability in itself means little if you can't facilitate and or guarantee.

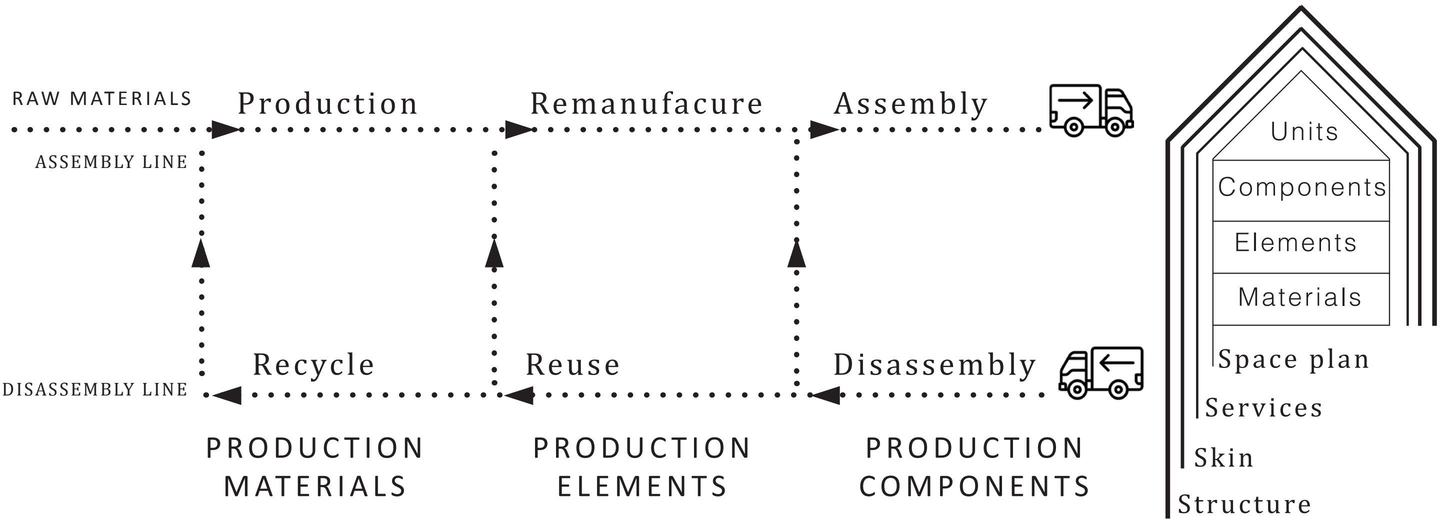


4.1.3 THE DISASSEMBLY LINE

Being able to gather units and disassembly it inside the factory it facilitate circularity. This is because it can be done systematically



The diagram below is a simplified representation on how it also can work. This is when you collect direct components and replaced on site. When the location of the building workst well then it is not necessary to take the units because the base of the building, the structure layer will last for a long time, when the other layers have multiple cycles the structure layer will still last.



4.2 Technical changes

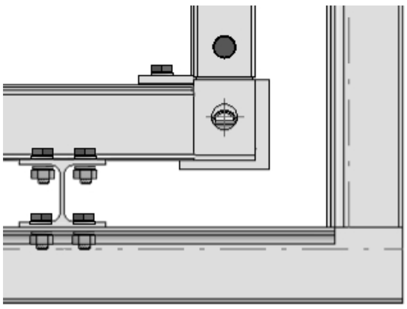
This chapter shows technical changes in some of the components. These changes do not have an effect on the overall design of the house. However they are important for the future reuse of the components.

4.2.1 IMPROVEMENTS TO STEEL FRAME

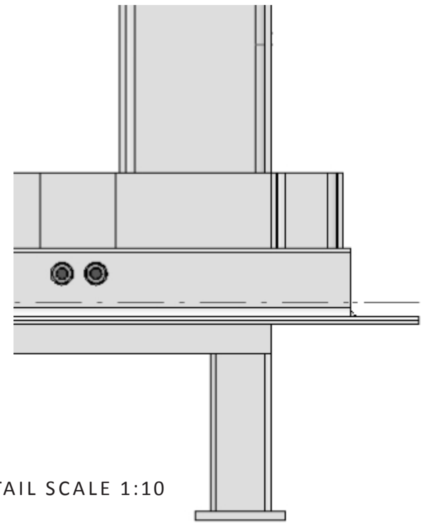
Although the most connections in the steel frame are bolted, there are still connection welded. These connections can be replaced by bolted connections. In the previous figure is shown the welded connections that can be replaced. Welding is often faster to make and it is cheaper then a bolted connection. However welding is not easy to separate the elements once you make such connection.

This new bolted connections are made in the L-profile that holds the brick facade. By turning these connections into bolted it becomes possible to detach the facade without needing to demolish it.

The new bolted connections will be around 800 euro more expensive than the welded connections.



HORIZONTAL DETAIL SCALE 1:10

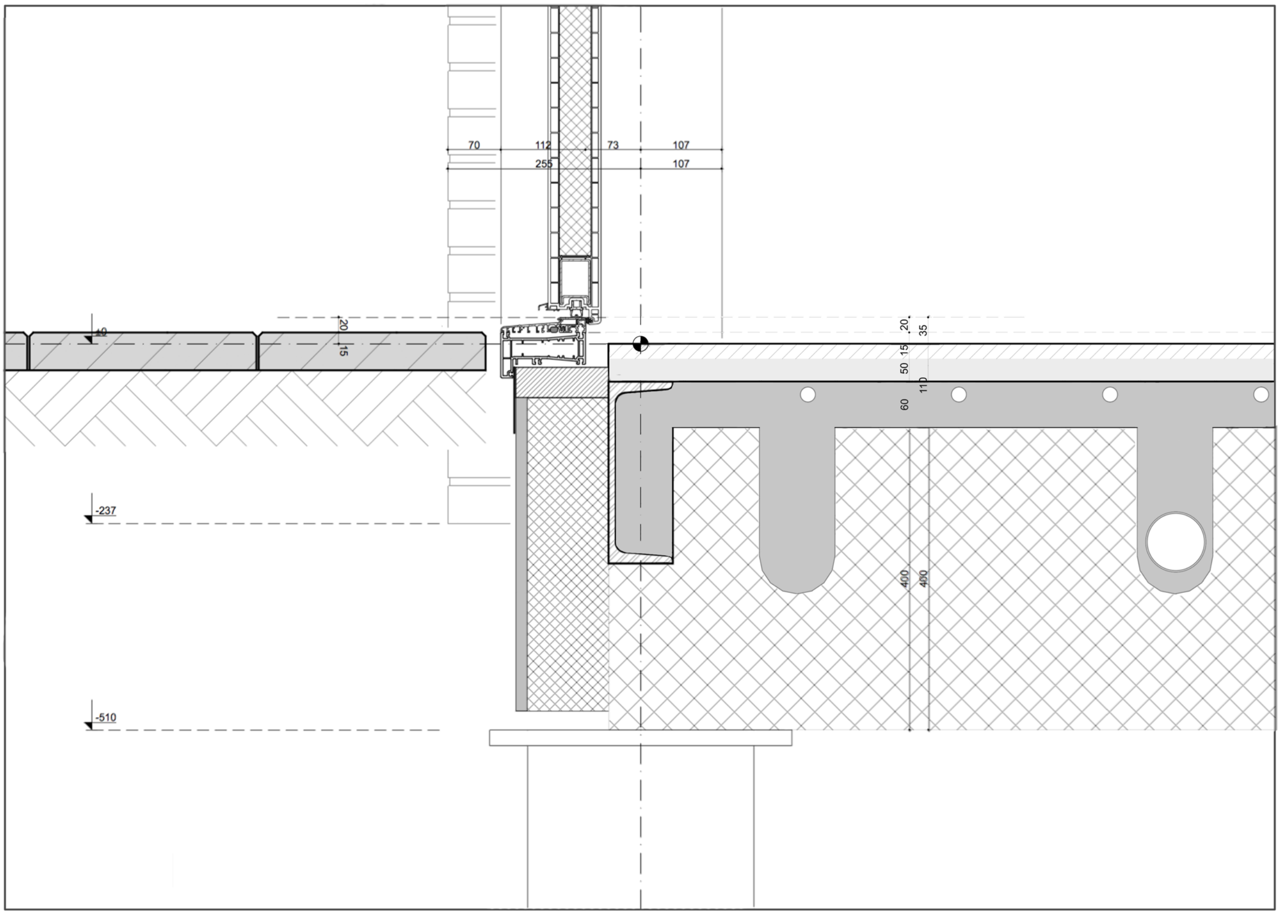


VERTICAL DETAIL SCALE 1:10

IN RED IS WHERE THE NEW BOLTED CONNECTION IS SITUATED.

4.2.2 IMPROVEMENTS TO CONCRETE FLOOR

DETAIL FLOOR CURRENT SITUATION

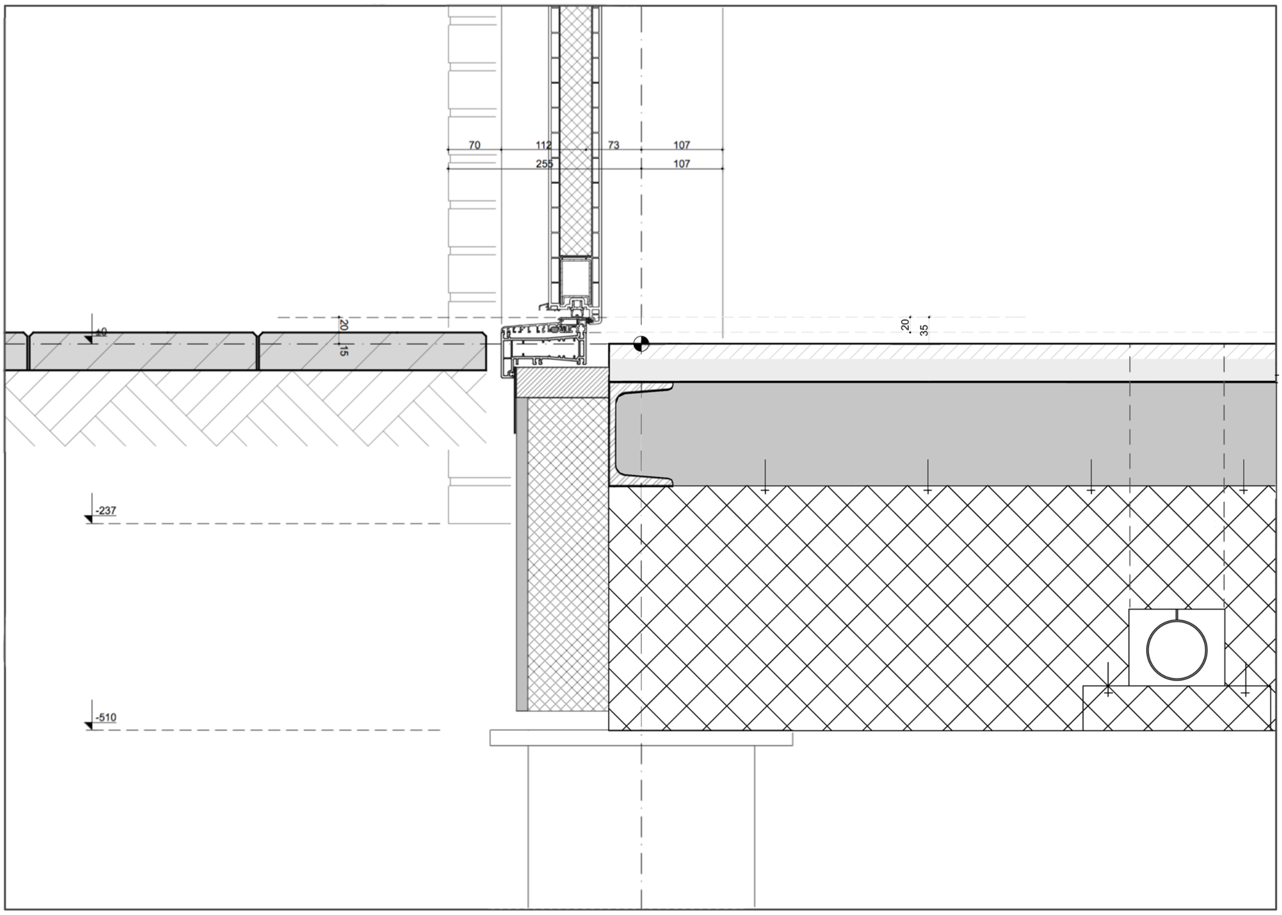


LEGEND

- Cement floor
- Concrete
- Insulation
- Soft wood
- Grid line

The detail above shows the current situation. As you can see the concrete is poured together with the insulation, the sewer pipe and the floor heating. The problem here is that it is very costly to separate those different elements and materials. When we separate and make it easy to diassemble it is more likely that the different elements and materials can be reuse instead of being demolished and turning into waste.

DETAIL FLOOR NEW SITUATION



LEGEND

- Cement floor
- Concrete
- Insulation
- Soft wood
- Grid line
- Gap

The detail above shows the new situation. As you can see the concrete is separate from the sewer pipe, insulation and there is no floor heating. The floor heating installation can be replaced for only infrared heating. Creating a gap in the floor it is also possible to replaced the sewer pipe with another pipe even bigger then the previous. This way future reuse is more likely because the floor is more prepared for change.

Making this changes in the floor is around 1000 euro more expensive than the current way.

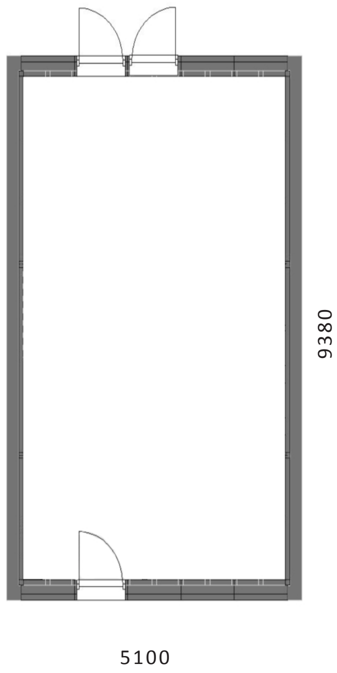
4.3 Design changes

This chapter shows some design changes in the house. These changes have an effect on the overall design of the house. They are important for the future reuse of the components.

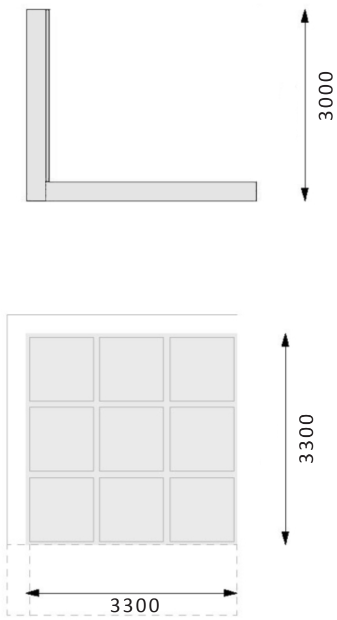
4.3.1 DIMENSIONS

Choosing the right dimesions has a big impact on the possibilities for future reuse. An option would be to create a base grid where we are able to standardize different components and create a catalogue. This will facilitate circularity because than you are able to change components later on. The base of the grid is a rectangular module width of 3300 by 3300 by 3000 height (mm). With two modules you are able to create one dwelling. By making additions different sizes of houses are possible. With this catalogue and the base grid we are able to create different compositions. And also transform the size in the future. Although this may sound promising this is not applicable for this system of contruction.

By choosing for example a fix dimension like 6X10 meters for the plan we are able to standirdize components and that facilitates future reuse. Altought a beneficial measure in the context of social housing 6x10 meters, it is not realistic to use only this grid because of the budget of different projects. The most used dimension for houses is 5100 by 9380mm. So my proposal is to only use from now on this dimension.



STANDARD DIMENSIONS FOR PLAN HOUSE



THE BASE GRID

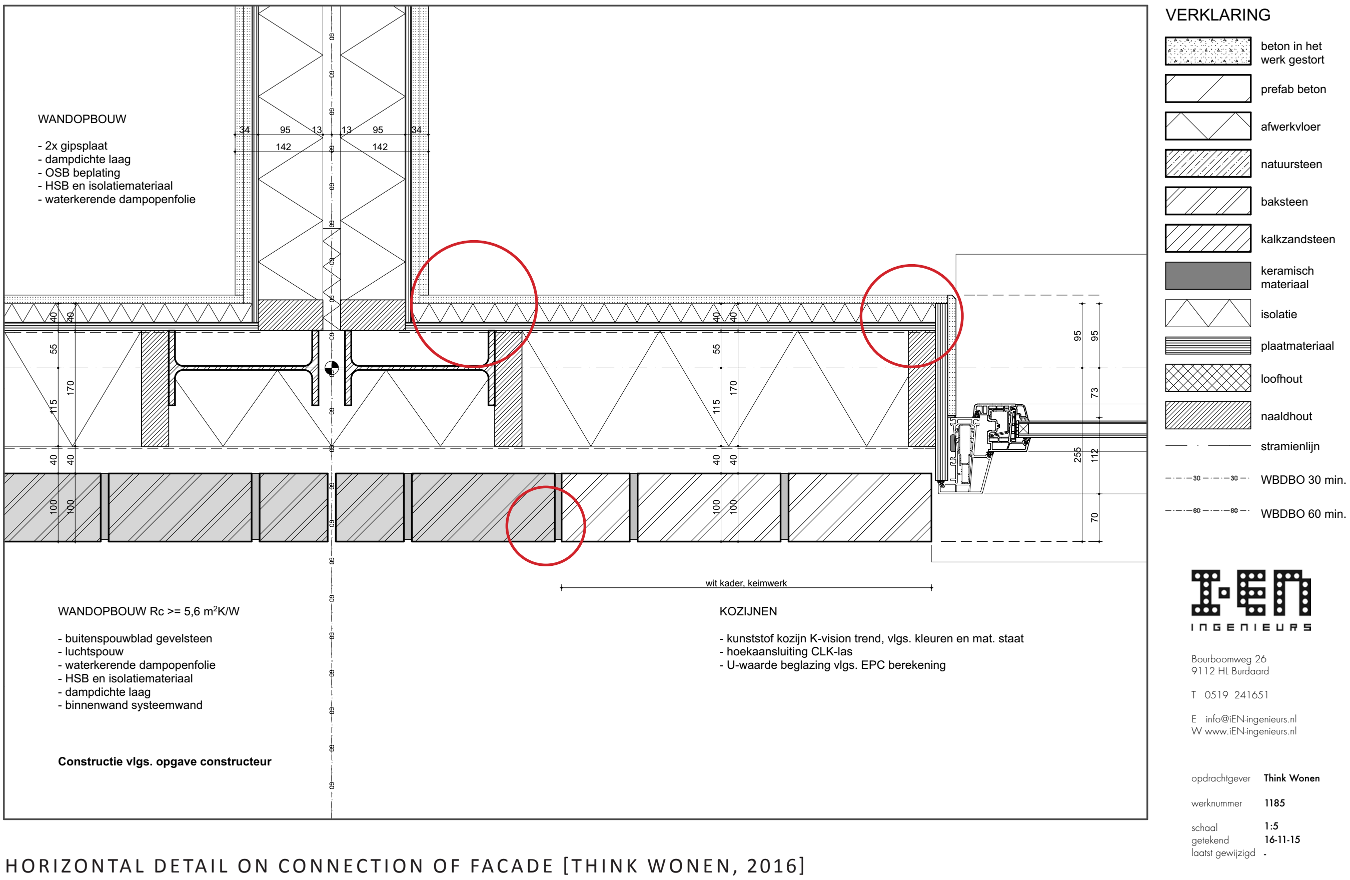
4.3 IMPROVEMENTS TO SKIN LAYER

By keeping the same dimensions of the structural layer there is still freedom in the architecture of the facade.The different elements can be combined endlessly among themselves. Therefore, various types of houses can be realized.

However to be able to reuse a facade you first have to be able to disassemble it without demolishing it. This is at this moment not possible. Also the different elements in a component needs to be able take it apart easily.

DIFFERENT FACADES POSSIBILITIES, MADE BY TWA-ARCHITECTEN [THINK WONEN, 2016]

DETAIL FACADE CONNECTION CURRENT SITUATION



HORIZONTAL DETAIL ON CONNECTION OF FACADE [THINK WONEN, 2016]

The current problem is that it is difficult to disassemble the different elements marked in red in the horizontal detail. By changing those connections and standardizing the facade component it will be easier to disassemble the facade.

An alternative for the traditional brick wall could be click-brick where cement mortar and murfor is not needed. Or change brick for another element, wood for example.

FACADE CONNECTIONS OF DIFFERENT ELEMENTS

WOOD FINISHING FACADE

Exchanging a whole facade is already possible and also already realize by TW in the project Blueprint homes Heerhugowaard. This project was realized by another construction company. But only a few years after the completion there were leakages and poor insulation an the facades needed to be replaced.

On the pictures below is shown that the facades from the other construction company were not made to be disassemble and had to be demolished. The elements of the facade components could not be used again creating a massive amount of waste. However it was possible to replaced the facade with a new one as one component.

BEFORE THE RENOVATION [THINK WONEN, 2016]

CONSTRUCTION PROCESS OF THE PREFAB ELEMENTS [THINK WONEN, 2016]

DURING THE PLACEMENT AND AFTER PLACING THE FACADE COMPONENTS [THINK WONEN, 2016]

4.4 FINANCIAL MODEL

This chapter dicuss a proposal for a new business model for the steel frame and the concrete floor (the structural layer). This model is based on the buy back model discussed in chapter 2.5.2

4.4.1 NEW MODEL FOR STRUCTURE LAYER (STEEL FRAME AND CONCRETE FLOOR)

Assuming that a housing association must write off a home after 50 years to 0 euro.

Assuming that TW will be able to buy back steel frame and concrete floor after 50 years for an agreed price by the time of the sale. TW will sell the house for 80000 euro and after 50 years TW buys it back for 14000 euro. TW will then make a new home and sells it back to the housing association for a market price at the time.

During this case study, a life span of 100 years is assumed, divided into two use cycles:

Use cycle 1: year 1 to year 50
Use cycle 2: year 51 to year 100

The structure layer is used two times, before it would be returned to the resource level. Setting the use cycle to 50 years leads to some complications. First it seems impossible for both the construction company TW as the client housing association to look in a 50 year future. No party is currently willing to agree on a contract covering such a period, it is also legally impossible at this moment (see Apendix D). Besides, agreeing on a residual value over that period seems impossible, since a calculation of yield over 50 years does not correspond to the reality. No one can make a realistic financial calculation over 50 years. A shorter use cycle does not fit either.

During the buyback the structure, TW would need to consider certain costs to be made in order to retrieve the steel frame and the concrete floor. For example: disassembly costs, transportation costs and storage costs.
It is likely that the need for steel will increase constantly in the coming years by 3% steel worldwide. [MetaalNieuws, 2014] Assuming that the price of steel will also increase the coming years respectively by 3% per year.

Here two scenarios will be discussed by the linear scenrio the assumption is made that after the house is fully depreciated to 0 euro, it will be demolished. By a more circular scenario TW will buy back the structure and reuse it in a second cycle. The caculations are based on a TW house type M of the case study in the previous chapter (see figure 27).

Steel chassis	€ 8000
Concrete floor	€ 6000
Total =	€ 14000
	(Including labor)

17,5 % of the total cost of a house is the structure, the steel chassis and the concrete floor.

Total house type M = € 80000

SCENARIO 1: TW LINEAR AFTER 50 YEARS

Total cost house type M	€ 80000
Demolition costs	€ 6000
Total cost House in 50years	€ 86000

86000/50 years = € 1720 depreciation costs per year

SCENARIO 2: TW CIRCULAR AFTER 50 YEARS

Total cost house type M	€ 80000
Buy back	- € 14000
Total cost House in 50years	€ 66000

86000/50 years = € 1320 depreciation costs per year

4.4.2 CONCLUSION

As can be seen the expected financial difference in two described scenarios is 86000 - 66000= 20000. This simple calculation shows that from a financial point of view it would be interesting to develop a project in a circular manner. It creates a win-win situation where the housing association gets a discount on the new house and TW makes more profit assuming that the steel price will rise. However this is not an accurate cauculation and most of the data are assumptions.

5. CONCLUSION

The main research question of this research was:

How can we improve the production process of social housing of the building company TW in order to facilitate circularity?

With the design proposal improvements the production process of TW has become more circular. This research is a nescessary start in the development of TW to change into a circular process. There is still a lot of work to be done to turn the production process of TW into a complete circular process. In order to facilitate circularity in the production process of TW we need to look into each building product or component of a house separate and see how we can create cycles with that specific component without loosing value. In this research an attempt is made to do so with the steel frame component, the concrete floor and the facade component.

The structure layer that consist of the steelframe and the concrete floor is for TW the most important layer because it is the most expensive part of the building. However it also has the longest lifespan, making it difficult to create cycles. Although in theory it could be possible it is very unlikely to happen. With the proposed changes in the structural layer it is easier in the future to harvest the different elements and materials. Making it more accessible for reuse or recycle. However this does not mean that the structural layer of TW house circular is. By creating one size chassis, steel structure it makes it easier to standardize the facade component.

For facade component a new connection detail of the facade with the steel frame is proposed. This makes it possible to replace the whole facade. This doesn't mean that this component have a circular process. However it makes it easier to create cycles with this component.

The design proposal changes comes with a price. One house will be around 1800 euro more expensive. This makes a house too expensive for social housing and these are only the first changes. Hereby we can conclude that it is not yet financially feasible to make the production of a social houses of TW more circular.

6. DISCUSSIONS

This chapter discuss in short some discussions points that are important for further research.

COSTS

From an economic point of view is not yet feasible to make the proposed changes in chapter 4. However there is a lot of potential to become a very profitable business case when changing to a circular process. The new model presented in chapter 4.4 shows a little the possibilities. Every different building product that is in a TW house needs to be reevaluated and see if a different business model is possible. For example, to turn into a service.

DIMENSIONS OF THE HOUSE

Choosing only one standard dimension will facilitate circularity. This makes it easier for in the future to reuse a component because it has the same dimensions and will not need changes to fit in another context. Also when choosing a bigger dimension for the floor sometimes it makes financial no difference. For example it is better to choose a width of 5100mm for the floor instead of 4800mm or 45000 because the price is the same. However the 5100mm is more likely to adapt in future situations. The discussion that appears here is the new role of the architect. When every component become standardized the architect is limited in design choices.

CHANGES IN THE FLOOR

Hereby is the discussion of the changes that are made in the floor, made the floor become circular. The changes which have been proposed for the floor are minimal, and it is still not completly circular. But with this change, it is easier in the future to retrieve the various elements and materials.

Another option could be to change the whole floor system. This also means changing material composition. A wood floor is easier to make changes in. The main reason for choosing a concrete floor in the Netherlands is because of the demand in the market. End users and clients prefer a concrete floor. The main reason for that is the different feeling from both floors.

THE END USER

Residents also benefit from the addition of flexibility in a home. Because you can easily change different components it become interesting for the user if he can make a particular choice. Resident may have a say in how he would like to the house to function.

7. REFLECTION

When I started this research I had two major problems, the need for more social housing and our current “take-make-use-dispose” linear (building) economy.
I started thinking that I was suppose to solve these problems, but in fact I was not able of solving them. Although in the initial phase the pretension was to do so, I realized scientific research is more about clarifying and describing the situation. Doing this we can come every time closer to a complete solution. So I started with a very broad subject and I found myself in a situation where it was difficult to direct my research. With the CE as the main theme in the research project was the delimitation of the research one of the biggest challenges throughout the project. As demonstrated in this study is the CE a broad concept. In the end I was able to frame my research and bring more depth into the research. I believe topics regarding the CE in the construction industry, could be perfected, reduced and better framed from the beginning.

Scientific research to a broad concept as the CE requires a good delimitation. Within this research choices are made on the behalf of the delimitation which in hindsight could also be seen as obstructive. The choice to focus on the process turns out not to be the most important part to investigate it and was still a very broad subject. It would have been better to have chosen from the beginning, just a building component to focus on.

Creating a CE in the built environment is a very new phenomenon and I don’t have a answer how to do it, in fact no one has it yet. However it is necessary to make this transition before it is too late and every step we take towards it is important.

There are only few practical examples regarding the CE in the building industry. Few information felt like to be available at the start of my research, and a lot of sources regarding the CE pointed to a single source: the Ellen MacArthur Foundation.

However as the research was progressing the amount of literature on this topic was overwhelming. Although there is so much knowledge on this topic this research shows how to really put that knowledge into practice. In this case a construction company that is willing to change the process into a more circular. It took me many hours to analyses the current information and use it correctly in the context of my own research.

This research shows how difficult it is to change a conservative industry such as the building industry. It involves a lot of different aspects that has to change in order to work in a new CE. But it also shows the possibilities of the impacts that a contractor can have by setting the standard.

Construction companies have the obstacle that they are locked into the current economic market system. Right now the building industry is not ready for the implementation of new models derived from the CE such as Product as service system. However when they start implementing some aspects of CE like broader standardization, it would reduce planning costs and construction risks.

Also implementing sale and buyback is not yet feasible. This is because the initial cost of the house will be higher and in an industry that is really driven by profit this is not feasible. Although the business case is based on sale and buy back this is also legally not yet possible.

Looking at the content of the research I believe that the legitimacy of the new design improvements and financial calculations to be debatable. Although many of the input variables have been validated by building company TW itself, small differences in these variables could mean the possible difference in being feasible or not feasible. Because these new kind of processes are new for TW, the input variables are likely to be an estimation instead of a correct representation of reality.

In general, I think the research process has been very interesting and enlightening. I enjoyed working close with the construction TW and seeing close the process. I particularly hope that my research will contribute to the search for an ideal circular building system.

8. RECOMMENDATIONS

Here are some recommendations for future research described in possible research topics:

- Further research into the standardization of components.

- Kitchen and toilet are often changed by a new user, further research on how to turn this process into a circular process.

- Research into dry connections and how to integrate in the units of TW.

- The effect on the architecture of dwellings regarding to the circularity.

- Business case on different components of a TW house and how it could work in a CE.

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APPENDIX A | EVALUATION TEMPORARY HOUSING

NAME CONSTRUCTION COMPANY TEMPORARY HOUSING	BUILDING TIME	FLEXIBILITY (DIMENSIONS)	FLEXIBILITY (ARCHITECTURE)	FLEXIBILITY (LAYOUT)	STACKABLE	DURABILITY	ENERGY USE
1 ALGECO	+	–	–	–	+	–	–
2 BARLI	+	–	–	–	+	–	–
3 BUSSMAN	+	–	–	–	+	–	–
4 CHS SPECIAL PRODUCTS	+	–	–	–	+	–	–
5 TW	+	+	+	–	+	+	+
6 DE GROOT VROOMSHOOP	+	–	–	–	+	–	–
7 BUKO	+	–	–	–	–	–	–
8 HEIJMANS ONE	+	–	–	–	–	+	–
9 IQWONING	+	–	+	+	+	+	+
10 DE MEEUW	+	–	–	–	+	–	–
11 DIRECT BOUW	+	–	–	–	+	–	–
12 ECOCASCO	–	–	–	–	–	+	+
13 FINCH BUILDINGS	+	–	–	–	+	+	+
14 DE HOMEVAST TSS - UNIT	–	–	–	–	–	–	–
15 HODES BOUWSYSTEMEN	+	–	–	–	+	–	–
16 JAN SNEL	+	–	–	–	+	–	–
17 KAVEL44	+	–	–	–	+	–	–
18 LANCET LIVING	–	–	–	–	–	–	–
19 KAVEL44	–	–	–	–	–	–	–
20 NEDERHOME	+	–	–	–	+	–	–
21 NEPTUNUS	–	+	+	+	+	–	–
22 PASAAN	–	–	–	–	–	–	–
23 STARCABIN	+	–	–	–	+	–	–
24 URSEM	+	–	–	–	+	–	–

APPENDIX B | PRIORITY MATERIALS IDENTIFIED IN EU SCOPING STUDY [BICKET, 2014]

	Material	Prioritised by	Scarcity and dependence	Environmental impact	Potential savings	Key opportunities and challenges	Identified as a priority?
Forestry & agricultural products	**Agricultural products & waste**	• TNO 2013 • WEF & EMF 2014 • McKinsey Global Institute 2011	High	High	High	Need and some scope for improvement - some feasibility issues	Priority
	Wood & paper	• WEF & EMF 2014	Medium	High	Medium	Need and scope for improvement	Priority
	Textiles	*None*[*]	Low	Medium	Medium	Some scope for improvement: collection rates	-
Minerals, chemicals and compounds	**Plastics**	• Arcadis 2010 • WEF & EMF 2014	Medium	High	*No info*[†]	Need and scope for improvement: purity (PET and polymers) and collection rates (polymers)	Priority
	Metals	• Arcadis 2010 • EMF 2012 • Green Alliance 2011 • TNO 2013 • McKinsey Global Institute 2011 • WEF & EMF 2014	High	High	High	Need and scope for improvement: purity, material efficiency and value recovery	Priority
	Phosphorus	• Green Alliance 2011	High	High	*No info*[†]	Need and scope for improvement: substitution and improved practices	Priority
	Rock	• WEF & EMF 2014	Low	Medium	*No info*[†]	Scope for improvement: reuse and recycling	-
	Glass & ceramics	• WEF & EMF 2014	Low	*No info*[†]	*No info*[†]	Scope for improvement: purity of recycled material	-
	Fossil fuels	• Arcadis 2010 • McKinsey Global Institute 2011	High	High	*No info*[†]	Substantial existing policy coverage; feasibility issues	-
	Other chemicals & compounds	• RLI 2013 • Arcadis 2010	Some high	High	Embedded in savings from improved recycled quality of other materials	Need for improvement: contamination and material purity repercussions for other materials and products (e.g. paper and plastics)	-

KEY [green] - Based on available information, outcome warrants priority consideration

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* *Not identified as a key priority amongst sources reviewed.*

† *Not addressed in sources reviewed; or due to lack of availability of comparable information.*

APPENDIX C | PRATICAL ASSESSMENT OF BUILDING LAYERS

This practical assessment was made per layer for one unit of the case study project. the assesment is based on 3 grades. Normal(2) doesn't have the priority to change. Better(3) is when a component is already facilitating circularity and Bad(1) are the things that needs to change.

ASSESSMENT STRUCTURE LAYER

	Structural frame (chassis)	Foundation	Floor
• Dimensioning facade grid	2	2	2
• Modular coordination	2	2	2
• Connections of foundation		3	
• Connections between elements	1	3	2
• Thermal and acoustic quality of floor insulation	3	2	2
• Fire resistance	3	2	2
• Geometry of columns and beams	2	2	2
• Shape of floor-plan	2	2	2

ASSESSMENT SKIN LAYER

	Facade	Separating wall	Roof
• Dimensioning elements	1	2	2
• Dismountable elements	1	1	1
• Insulation components	1	1	1
• Daylight entry	2	2	
• Reuse windows	2	2	
• Size of elements	1	2	2

ASSESSMENT SERVICE LAYER

	Prefab toilet	Heating	Kitchen	Electrical	Ventilation
• Dimensioning shafts	1	2	2	2	2
• Dismountable installations components	1	3	2	2	3
• Capacity of installations • Facilities	1	1	2	2	2
• Possibility to upgrade components	1	2	2	1	2

ASSESSMENT SPACE PLAN LAYER

	Partition walls	Stair	Interior doors	Interior finishing
• Dimensioning Partition walls	2	2	2	2
• Connections partition walls, stair and doors	1	1	2	
• Reuse of stair and interior walls	1	1	2	2
• Size of components	2	2	2	2
• Individual finishing	2	2	2	2

DE JURIDISCHE ASPECTEN VAN DE EIGENDOMSOVERDRACHT

Partijen kunnen in principe afspreken wat zij wensen. Dit wordt het beginsel van contractsvrijheid genoemd. De overeenkomsten komen tot stand door wilsovereenstemming. Het Burgerlijk Wetboek begrenst deze vrijheid. De inhoud of de strekking van een overeenkomst mag niet in strijd zijn met de goede zeden of openbare orde en/of de wet.[1] In art. 3:85 Burgerlijk Wetboek wordt bepaald dat overdracht onder tijdsbepaling niet mogelijk is. Het is dus niet mogelijk om en goed aan iemand over te dragen voor bijvoorbeeld 10 jaar. In de door Think voorgestelde constructie gaat het om een ontbindende tijdsbepaling. [2]

Omdat overdracht voor een bepaalde tijd in strijd is met de wet gaat de eigendom van de woning hierdoor niet over. Dit komt omdat wanneer er wordt afgesproken dat de woning voor 50 jaar wordt overgedragen er geen sprake is van een geldige titel. Voor een geldige overdracht van roerende en onroerende zaken is echter op grond van art. 3:83 een geldige titel, levering en beschikkingsbevoegdheid vereist. Dit wordt ook wel het causale stelsel genoemd. Zonder geldige titel kan er dus geen geldige overdracht zijn.

De wet bepaalt dat een verbintenis tot overdracht voor een bepaalde tijd van rechtswege als een verbintenis tot vestiging van een tijdelijk vruchtgebruik ten behoeve van de verkrijger geldt. Van rechtswege betekent dat dit automatisch gebeurt. Vruchtgebruik betekent dat iemand die geen eigenaar is van bijvoorbeeld een woning, hier toch gebruik van kan maken. Je bent dan de vruchtgebruiker van de woning. Iemand anders, in dit geval Think Wonen, is de 'blote eigenaar', maar zij kunnen niet veel doen met dit eigendom omdat de vruchtgebruiker het recht heeft gebruik te maken van de woning. Vruchtgebruik kan wel voor een bepaalde periode worden afgesproken.

Wel is het mogelijk dat Think een goed verkoopt onder een tijdsbepaling. Verkopen is dus iets anders dan overdragen. Het sluiten van de koopovereenkomst gaat vooraf aan de overdracht (lees: levering) van een goed. Think kan dus met de woningbouwvereniging afspreken dat de woning na 50 jaar weer terug moet worden overgedragen aan Think. Indien de woningbouwvereniging na 50 jaar zich niet aan deze verbintenis, ook wel de verplichting tot terug levering, houdt kan Think ten eerste nakoming vorderen. Indien de woningbouwvereniging de afspraak alsnog niet nakomt is er sprake van een wanprestatie en kan Think schadevergoeding eisen. Ook is het mogelijk om via de rechter de woningbouwvereniging alsnog te dwingen om de gemaakte afspraak na te komen.

Gelet op het bovenstaande geconcludeerd ik dat Think niet de woning voor 50 jaar kan overdragen. Gebeurt dit toch dan wordt er een vruchtgebruik gevestigd. Think zal daarom de woning zonder tijdsbepaling moet overdragen als Think geen eigenaar meer wenst te zijn van de woning. Wel kan er een afspraak tussen partijen worden gemaakt die inhoudt dat de woning na een aantal jaren moet worden terug geleverd. Om de bewerkstelligen dat het wel mogelijk is om een goed over de dragen voor een bepaald aantal jaren dient te wet te worden gewijzigd. Of de wetgever hiertoe bereid is is de vraag. Gesteld kan worden het recht uiteindelijk dienend moet zijn aan de behoeftes van de maatschappij, met name juist in het kader van duurzaamheid.

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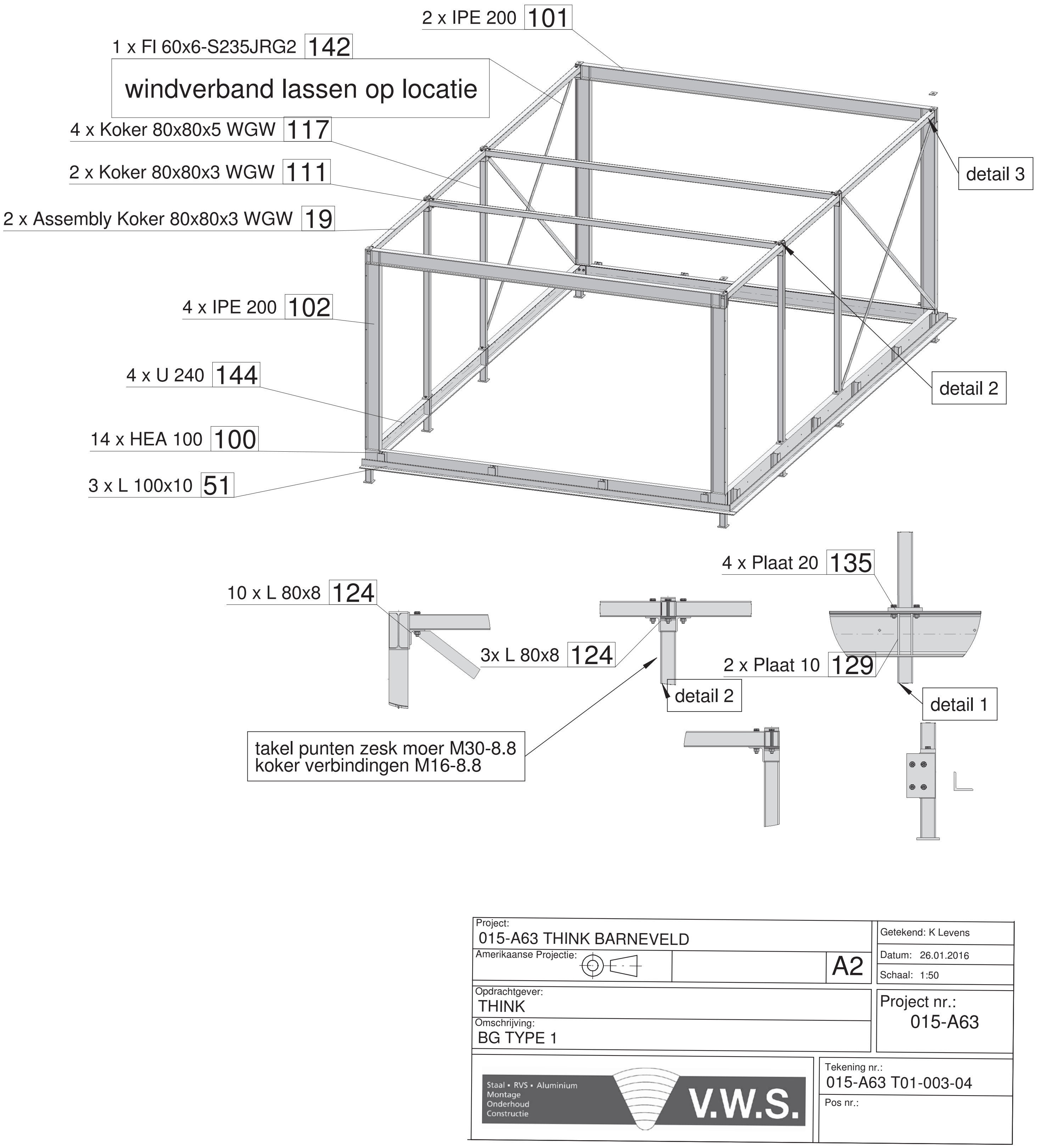
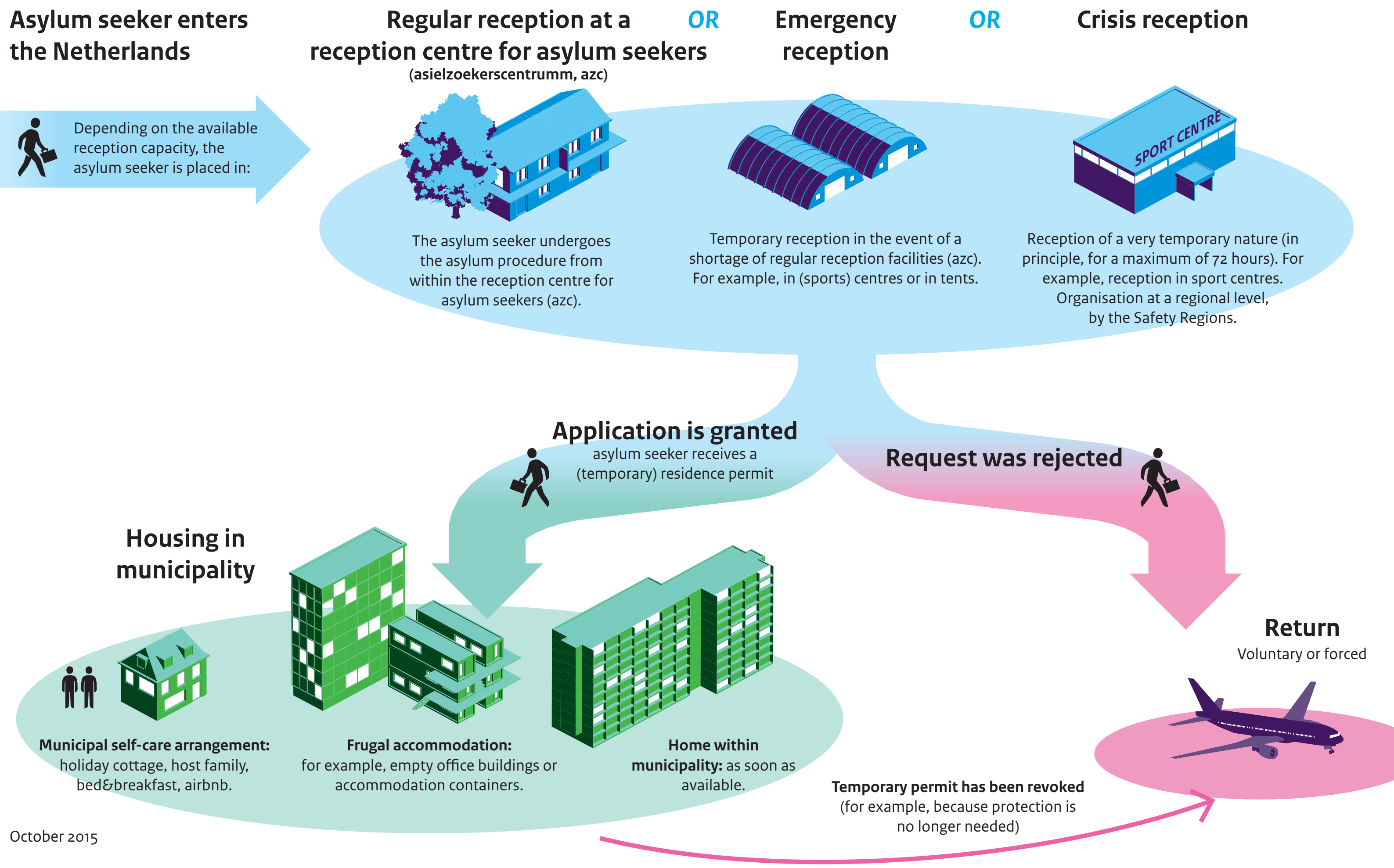
[1] Hijma, Rechtshandeling en Overeenkomst, Deventer: Kluwer 2013.
[2] Groene Series, Vermogensrecht, art. 3:85 BW, aant. 5.5

APPENDIX E | CURRENT STRUCTURAL FRAME



APPENDIX F | Reception of asylum seekers in the Netherlands [Ministry of Security and Justice, 2015]



APPENDIX G | THE CE FRAMEWORK

INDUSTRIAL ECOLOGY [FORSCH & GALLOPOULOS, 1989]
Industrial ecology seeks opportunities for waste- and pollution reduction in the material-intensive industries by exploiting the use of the low-value products, waste as raw materials for others [Ayres & Ayres, 2002].
• Waste mining
• Dematerialisation
• Repair- re-use, re-manufacture and recycle
• Design for the environment: Products should be designed for disassembly, reuse and minimal impact on the environment
• Substitute scarce materials by renewable materials
• Reduce, and with time eliminate heavy use of non-biodegradable materials

REGENERATIVE DESIGN [LYLE, 1996]
Supply systems for energy and materials have to be continuously self-renewing in their operation.
• Operational integration with natural processes and by extension with social processes
• Minimum use of fossil fuels and man made chemicals except for backup applications
• Minimum use of non-renewable resources except where future reuse or recycling is possible and likely
• Use of renewable resources within their capacity for renewal
• The environment should be able to absorb the composition and volume of waste without damage.

FUNCTIONAL ECONOMY [STAHEL, 1997]
An economy that aims for optimization of the use value of goods and services for the longest possible period of time while consuming as few material resources and energy as possible.
• The smaller the life-cycle loop of a product or material, the more economically profitable and resource efficient it will be: The more a product or material could be re-used after it expires its original use, the more the material's productivity and longevity will be.
• Product or material loops have no beginning and no end: Waste does not exist. The stock of existing goods within the loop should be constantly monitored and optimized in order to maintain value.
• Reduction of the speed of the resource flows: Long life goods increase the efficiency of managing the existing stock of materials. Through cascading and cannibalizing, new product could be derived from waste.
• Reduction of volume of the resource ow: Goods should be modular and multi-functional.
• Reduction of the volume and speed of the resource ow: Selling service instead of goods

BIOMIMICRY [BENYUS, 1997]
Biomimicry encompasses the study of what we can learn from the nature instead of what we can extract from it.
• Evolve to survive: Strategies that are proven to work, should be replicated and improved.
• Be resource (material and energy) efficient: The use of multi-functional design and low energy processes should be stimulated. All used materials have to be recycled.
• Adapt to changing conditions: Maintain integrity through self-renewal, and embody resilience through variation, redundancy, and decentralization
• Use life-friendly chemistry
• Be locally attuned and responsive
• Integrate development with growth: build from the bottom-up

CRADLE TO CRADLE [BRAUNGART & MCDONOUGH, 2002]
A design framework which involves technical and biological materials which are wholly healthful and regenerative, and relies on renewable energy. Besides reducing the organisation's negative impacts, Cradle to Cradle aims to create a fully positive footprint on the planet (environmental, social and economic).
• Waste equals food: Everything is a nutrient for something else.
• Use the current sun income: Use fully renewable energy.
• Respect diversity: Diversity makes a system more resilient. Species, cultural and innovative.

BLUE ECONOMY [PAULI, 2010]
The blue economy is a philosophy of alternative business models by using cascading systems in which waste forms the input to create new cash flows. Blue economy has a total of 21 principles, of which the most important ones have been listed below.
• Substitute something with nothing: Question any resource regarding its necessity for production
• Natural systems cascade nutrients, matter and energy, by means waste does not exist. Every by-product could be the beginning for a new product.
• Use what locally is available
• Nature provides room for entrepreneurs
who do more with less: Nature is contrary to monopolization.
• Nature is constant in change: Innovations take place in every moment.
• Natural systems are interconnected and evolve towards symbiosis.