YRKESHÖGSKOLAN NOVIA

Circular Economy

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Abstract

This is a report written as part of the EPS project at Novia UAS. The report is divided in three main parts and works as a pre-study for the EU funded project ‘Circular economy (CE): a game changer for the wood building industry (2018-2020)’, part of the Botnia-Atlantica program researching implementation possibilities for circular economy in the Ostrobothnia-region.

A general introduction to CE defines its characteristics as restorative and regenerative, aiming to keep the highest value at all time. CE is further clarified with a deeper explanation as well as the advantages and disadvantages of it.

Based on the criteria for CE and the tasks given by the customer of the project, different, resource-efficient buildings are listed and presented. The list contains six CE-inspired buildings that are located in Denmark, Finland, Germany and the Netherlands, outlining information about their background, supply chain, influences and conclusions.

Language: English Key words: Circular Economy, European Construction industry

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List of abbreviations

3D	:	3-Dimensional
AG	:	Aktiengesellschaft, in English: stock corporation
B.V.	:	Besloten Vennootschap (private company)
BREAAM	:	Building Research Establishment Environmental Assessment Method
C2C	:	Cradle to Cradle
CAD	:	Computer-Aided Design
CAM	:	Computer-Aided Manufacturing
CE	:	Circular Economy
CEO	:	Chief Executive Officer/Chairman
CI	:	Construction industry
CLT	:	Cross-Laminated Timber
CNC	:	Computer numerical control
DEA	:	Danish Energy Agency
EESC	:	European Economic Social Committee
EI	:	Energy Index
EIB	:	European Investment Bank
EPAL	:	European Pallet Association
EPC	:	Energy Performance Coefficient
EPEA	:	Environmental Protection Encouragement Agency
EPS	:	European Project Semester
ETA	:	European Technical Approvals
FSC	:	Forest Stewardship Council
GDP	:	Gross Domestic Product
GWP	:	Global warming potential

ICT	:	Information and Communication Technology
LCC	:	Life Cycle Costing
LED	:	Light Emitting Diode
LEED	:	Leadership in Energy & Environmental Design.
NGO	:	Non-Governmental Organisation
NOM	:	Zero on the meter
PEFC	:	Programme for Endorsement of Forest Certification Schemes
PPP	:	Private Public Partnership
PV	:	Photovoltaic
PVC	:	Polyvinyl chloride
R&D	:	Research and Development
ReSOLVE	:	Regenerate, Share, Optimise, Loop, Virtualise, Exchange
SDG	:	Sustainable Development Goals
SME	:	Small and medium-sized enterprise
SPF	:	Spray Polyurethane Foam
SWOT	:	Strengths, Weaknesses, Opportunities, Threats
TCO	:	Total Cost of Ownership
UAS	:	University of Applied Sciences
UN	:	United Nations
UV	:	Ultraviolet
VOC	:	Volatile organic compounds
WRAP	:	Waste and Resources Action Program
ZAE	:	Centre for Applied Energy Research

1 Introduction

The following chapter provides an overall introduction into the topic, with a description of EPS and an overview of the project. There is an explanation about the origin of the project as well as the project charter, project constraints and exclusions. The time and cost management part include the project schedule, workload, time and budget follow up. The risk management and the project closing provide the lessons learned. At last a reflection on the teamwork is added, based on the Strengthfinder workshop and Belbin results.

1.1 European Project Semester

The European Project Semester (EPS) is a multi-national programme that is offered by 18 universities in twelve countries within Europe. The target groups are students studying in the field of engineering as well as students from other faculties. The basic motivation for establishing such a system is globalization. The ongoing integration within Europe demands young and trained professionals. Aside from the core skills, there is also a need for expertise in the fields of cross cultural communication, social skills and team skills. As the project teams are multi-disciplinary and multi-national, EPS provides the opportunity to train both the education and the multi-cultural team working part.

Beside working on a given project in teams there are also courses such as teambuilding, project management, the Strengthfinder workshops, English academic writing and the local language Swedish. The working language for all oral and written communication during the semester is English.

In 2017 a total of 17 students from Finland, France, Germany, the Netherlands and Spain attend the EPS program at Novia University of Applied Sciences (UAS) in Vaasa. The topics offered in the autumn semester 2017 are: 3D Printing, circular economy (CE), Tomato Picker and Wet Grain Packaging. (Nylund & Ehrs, 2017)

1.2 Overview and Background

This chapter contains the project description and background as well as the project purpose. There is also the project charter provided which has been approved by the team and the coaches in the beginning of the project. The constraints and exclusions outline the borders of the project.

1.2.1 Project description & project background

The EPS topic ‘circular economy’ is settled in the field of research projects. The following text describes the project idea and background. It was created and handed over to the team of supervisor Stefan Pellfolk and customer Annika Glader.

“Recycling is a precondition for circular economy. Materials and resources can be recycled, returned back to the economy and used again. Material and resources that are now considered as waste, can be reinjected to the market. To fully realize the potential of these so called secondary raw materials, we have to remove the existing barriers to their trade and our way of thinking. Only then will the market be able to use the full potential of circular economy.

Construction industry deals with large amounts of material flows. Over the next ten years, the demand for global construction is expected to increase by 70 %. This is a challenge in a world where resources are becoming scarce. For companies, this means introducing new business models based on maintenance, repair, re-use, refurbishing, remanufacturing and recycling. For customers, this means replacement of worn products with sustainable products or services. The goal is to maximize the use of renewable materials within biological systems, and to extend the life of non-renewable materials within technical systems.

Circular economy is about looking at a system as a whole and seeing how it is all connected. This involves both company and customer perspectives. Ensuring that supply meets demand and demonstrating the role of material development and product design are essential for achieving a shift towards circular economy. Customers must demand sustainable products and services, and industry must offer them. Since circular economy is based on the idea of material circulation, the customer must be included in the process in order to succeed with truly circular economy innovation.

The original project tasks:

Research the implementation of CE in the European Construction industry:

- regional differences, why?
- is CE included in agreements and contracts;
- CE supply chain, find examples and key actors;
- ‘end users’ involvement strategies;
- CE property maintenance solutions in order to extend building lifetime.

1. Find good examples of CE-thinking in the European real-estate market:

- biological- or technical cycle (or both);
- best practice cases;
- economic incentives.

2. Money makes the world go around, and will it make the economy circular as well?

- present your own business idea.”

(Pellfolk & Glader, 2017)

1.2.2 Purpose of the project

The project outcome will be used as a pre-study for an EU (European Union) funded project called ’Circular economy: a game changer for the wood building industry (2018-2020)’.

This project is part of the Botnia-Atlantica EU program (2014-2020) that finances cooperation projects between regions in Sweden, Finland and Norway (see Figure 1) (European Union, 2017).

Figure 1. Map of Scandinavia (European Union, 2017)

2 Introduction Circular Economy

This chapter explains the basics of CE, advantages and disadvantages of CE, influencing factor(s) and requirements complemented with CE examples.

2.1 Circular economy definition

The following paragraphs show different definitions for the term ‘circular economy’:

The Ellen Macarthur Foundation understands circular economy as "restorative and regenerative by design, [which] aims to keep products, components, and materials at their highest utility and value at all times." (Ellen Macarthur Foundation, 2017)

For the Waste and Resources Action Program (WRAP) circular economy is about keeping "resources in use for as long as possible, extract the maximum value from them whilst in use, then recover and regenerate products and materials at the end of each service life." (WRAP, 2017)

On the website of the European Commission, CE is defined as an economy that maintains the value of products and materials for as long as possible. "Waste and resource use are minimized, and when a product reaches the end of its life, it is used again to create further value." (European Commission, 2017)

2.2 From linear to circular economy

What all definitions above have in common and what the name circular economy implies is the trading of materials, products and services in closed loops, so to say ‘cycles’ (see Figure 2, right). Opposite of CE is the linear model of production and consumption (see Figure 2, left), also known as the ‘take-make-dispose’ model which dominated the economies worldwide for the past centuries.

Within a linear economy, products are made from raw materials and after its use any waste is thrown away. The reason why linear economy has been widely implemented until now is because it was the easiest way to provide economic growths by using large quantities of cheap, easily accessible materials and energy. Nowadays, things have changed and resources are finally perceived as finite. Price volatilities, supply chain risks and growing pressure on resources are now reasons for the need of circular economy.

The aim of CE is to decouple global economic development from finite resource consumption and eliminate waste. There needs to be an understanding that cycles cannot longer be seen separate from each other, but influence each other. This creates the need for system thinking, which means products must be designed and produced in a certain way so the value of components remains qualitatively preserved, e.g. through eco-design, sharing, re-using, repairing, refurbishing and recycling. At the end of lifetime, the initial resources or raw materials can then be returned into the circulation.

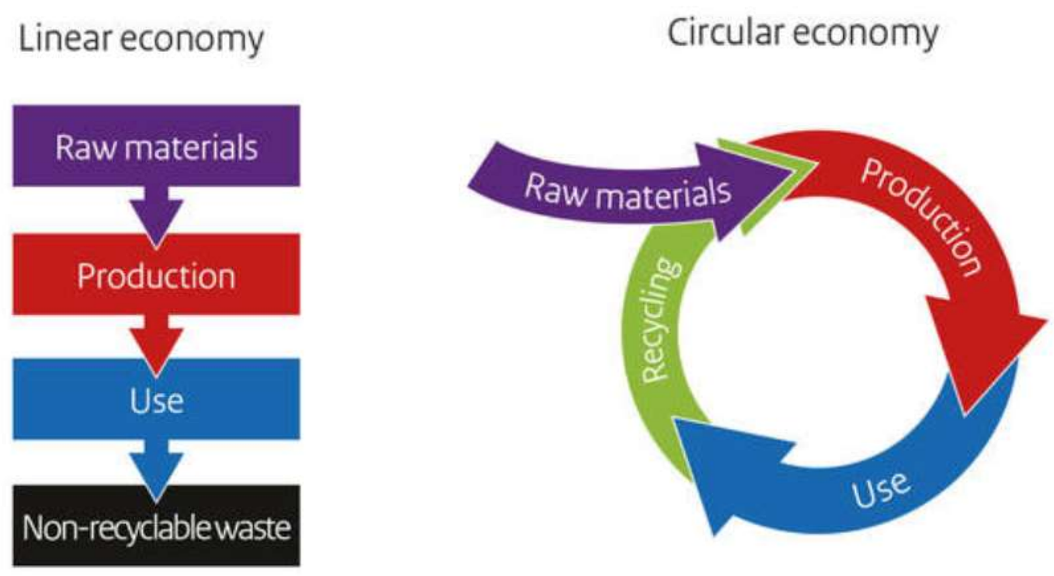


Figure 2. Linear economy vs. circular economy (Government of the Netherlands, 2017)

2.3 Two cycles

Circular economy can be divided into two cycles:

- biological cycle; and
- technical cycle.

Figure 3 shows consumption products belonging to the biological cycle in circular economy. This means that resources are regenerated and the flow of biological nutrients is encouraged while not exceeding the capacity of the natural systems. " In the biological, life processes regenerate disordered materials, despite or without human intervention" (Ellen MacArthur Foundation, 2015). As a result, the value of the natural capital is kept and the requirements for regeneration are met.

On the other hand, products that do not fit in the biological cycle are counted to the technical cycle. At the end of their lifetime these products are recovered and restored.

(Ellen MacArthur Foundation, 2015)

Figure 3. The two cycles of circular economy (Beckers, 2016)

2.4 Three key principles

According to the Ellen MacArthur Foundation, circular economy follows three main principles, which can also be seen in Figure 4:

> Principle one: 'Preserve and enhance natural capital by controlling finite stocks and balancing renewable resource flows.'

This means resources are selected with renewability and efficiency of products and services in mind. It is also an approach of circular economy to create conditions for regeneration, for example soil.

> Principle two: 'Optimise resource yields by circulating products, components, and materials at the highest utility at all times in both technical and biological cycles.'

The aim is to keep the value of resources used in products as long as possible as high as possible. This means the focus for developing products should be on extending lifetime and on the other hand on remanufacturing, refurbishing and recycling.

> Principle three: 'Foster system effectiveness by revealing and designing out negative externalities'

The negative human impact on the nature, such as air and water pollution, land use, release of toxic substances must be reduced to a minimum.

(Ellen Macarthur Foundation, 2017)

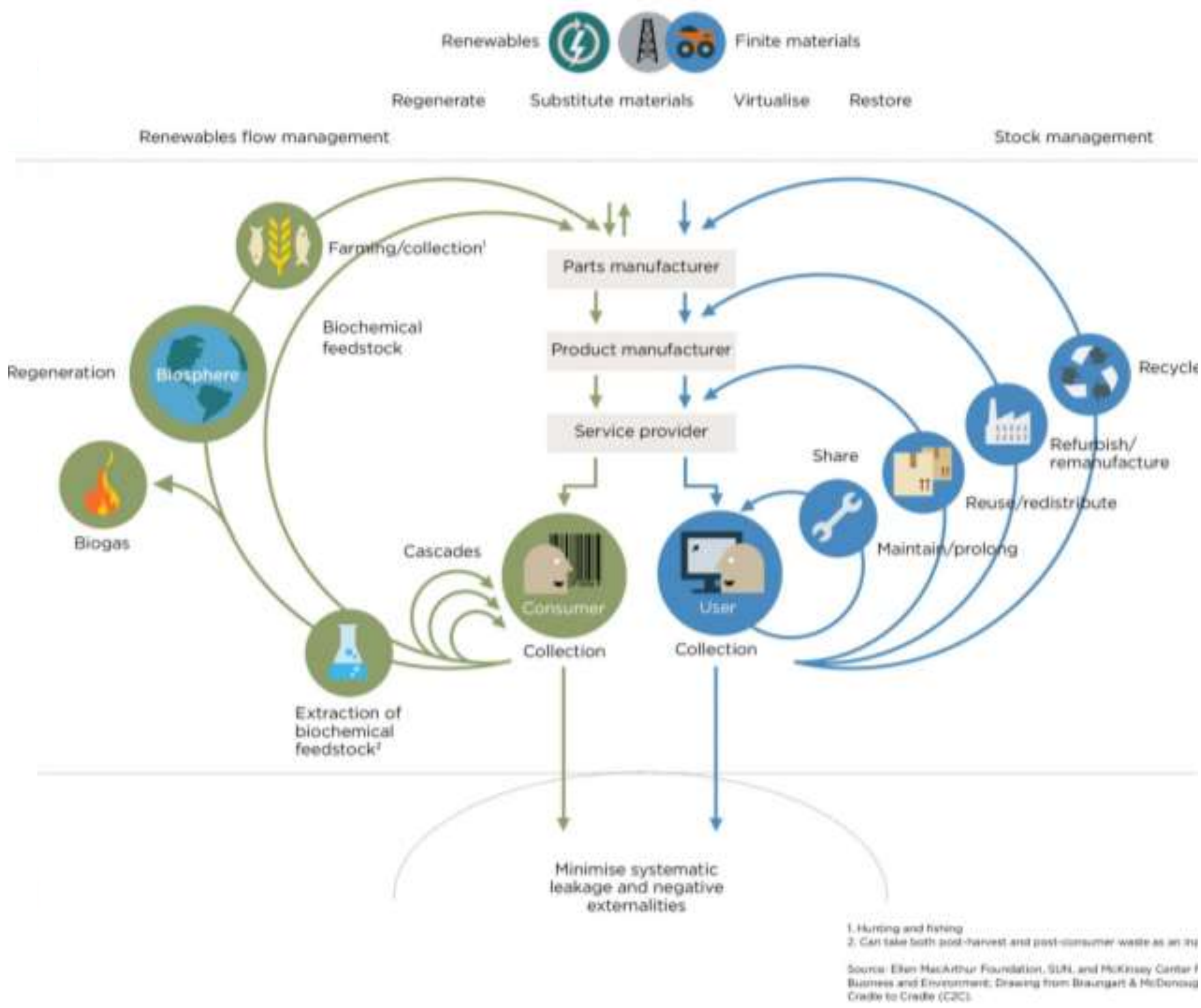


Figure 4. Two cycles of circular economy in detail (Ellen Macarthur Foundation, 2015)

2.5 ReSOLVE framework

The ReSOLVE framework is based on the three principles of circular economy. It is a set of business actions meaning that "each of the six actions represents a major circular business opportunity" (Ellen MacArthur Foundation, 2015). The aim of every action is to use the existing assets and increase their lifetime by shifting the finite resource use to the use of renewable sources (Ellen MacArthur Foundation, 2015).

Figure 5, next page, explains the ReSOLVE framework by giving short explanations to the action key words 'Regenerate', 'Share', 'Optimise', 'Loop', 'Virtualise' and 'Exchange'.

Figure 5. ReSOLVE framework (Ellen MacArthur Foundation, 2015)

2.6 Product / service requirements

To make a circular economy work, products or services must meet new requirements. Several demands are listed below and visualized in Figure 6.

- **Increased product lifetime**: long product lifetime can be increased through high quality, ageless design, modular construction and easy maintenance and reparability (Hartmann, 2017);
- **Use of renewable energies and resource efficiency**: products and services need to be as resource efficient as possible while being produced or provided using renewable energy sources;
- **Extending value chain**: circular economy moves away from the typical sales model, where the value chain ends with the delivery of the product, to leasing and rent models, where services are provided and value is added when the customer already owns the product. (Lutter, et al., 2016)

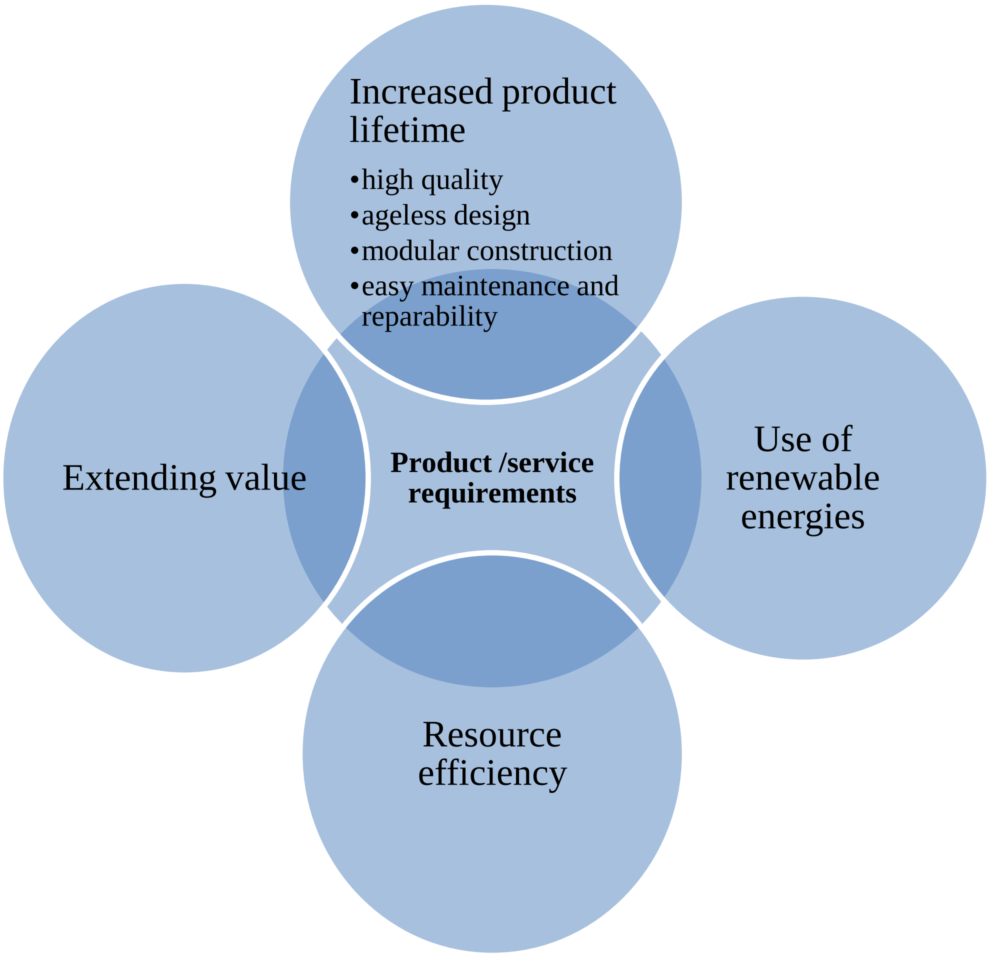


Figure 6. Product/ service requirements

2.7 Reasons for circular economy

There are many reasons why the circular model needs to be implemented in our economy. The following text shows only some of the main motives:

- **Growth of world population**: The significant growth of the population worldwide demands for solutions in the field of food, water and prosperity preservation;
- **Urbanisation**: Since more people are residing in cities, making CE more feasible, e.g. through cheaper sharing services and bigger supply of end of use materials to be recycled; (Ellen MacArthur Foundation, 2015)
- **Natural systems degradation**: The linear model which was practiced for a long time and still is 'state of the art' for some companies has an enormous negative impact on the environment. The Ellen MacArthur Foundation describes a selection of four elements contributing to the environmental pressure humans put on the environment and their impacts (Ellen MacArthur Foundation, 2015):
    - **Climate Change**: The "risks of climate change to human livelihoods and health, agricultural productivity, access to freshwater and ecosystems include: increased storm surges, coastal flooding and sea level rise; inland flooding; extreme weather events; extreme heat; and the loss of marine, coastal, terrestrial and inland water ecosystems" (Ellen MacArthur Foundation, 2015);
    - **Loss of biodiversity and natural capital**: The biodiversity declines results into losses in the value of ecosystem services;
    - **Land degradation**: In spite of increased fertiliser usage, the "agricultural productivity growth has been steadily declining" (Ellen MacArthur Foundation, 2015);
    - **Ocean pollution**: The mass of plastic waste and other rubbish in the oceans endangers, reduces or already destroys biodiversity and valuable materials, but also affects the fisheries sector and tourism in a negative way.
- **Limited amount of resources leading to price risk and supply risk**: The environment provides a limited amount of resources. Continuing with the linear economy would at any time mean, that we run out of raw materials. The shortage of resources is already visible in the increasing prices of raw materials like oil. Due to the difficulty of estimating how long the reserves will last, it is of paramount

importance to save the remaining reserves and reuse the already used resources; (Ellen MacArthur Foundation, 2015)

- **Decrease of lifetime of products**: The lifetime of products is steadily decreasing since consumers want new products more quickly and are using their old products for a shorter period of time. Consequently, more and more products have to be pushed on the market in order to satisfy the customers demand, while at the same time old products turn into non- or poorly-recyclable waste. To meet both challenges - satisfying the customer with continuous new products and reducing or eliminating waste of old products - circular economy is the answer;
- **Value loss**: In today's economy, a lot of product value is wasted, for example: waste-based energy recovery captures only five percent of the original raw material value (Ellen MacArthur Foundation, 2015).

Figure 7 sums up the points mentioned above and shows main reasons for the implementation of circular economy.

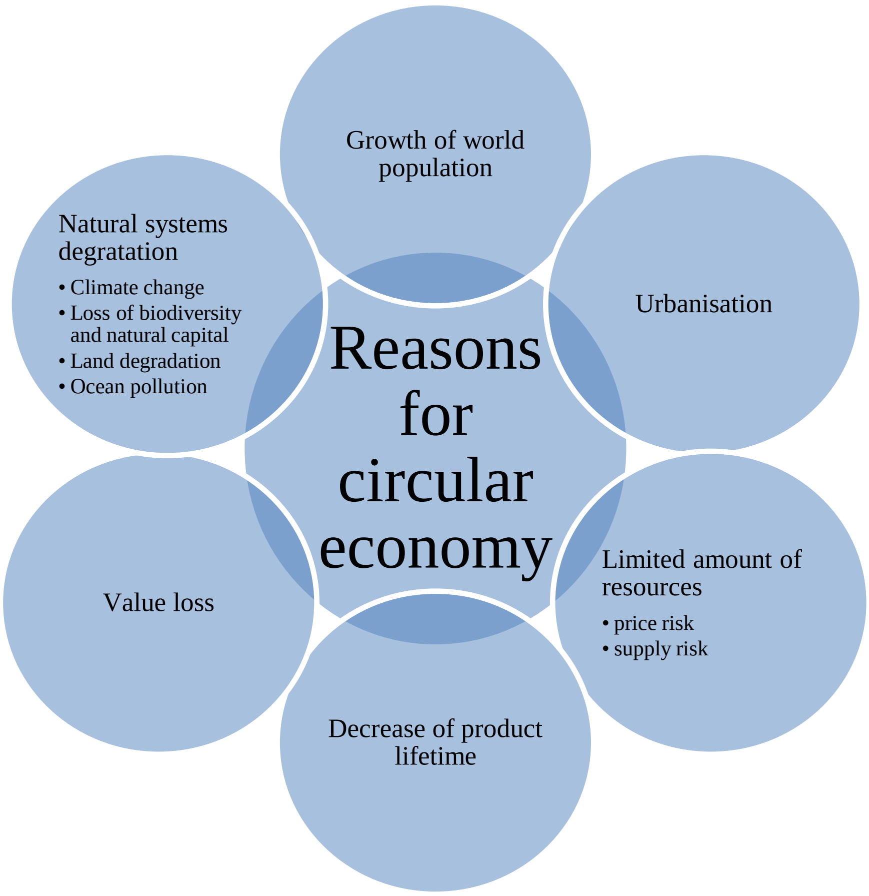


Figure 7. Reasons for circular economy

2.8 Linear economy vs. circular economy

Table 1 compares the linear model to the circular economy. The categories which are considered are:

- '**Step plan'**: what is the overall approach of the model?
- '**Value chain'**: where does the value chain end?
- **'Waste'**: is waste produced?
- **'Lifetime of pure materials'**: how long/often are pure materials used for (different) products?
- **'System boundary'**: what time span does the model consider?
- **'Sustainability'**: which actions are taken to ensure sustainability
- '**Quality of reuse practices'**: what reuse practices uses the model and what impact does it have on the value of the finite resources?

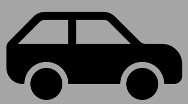
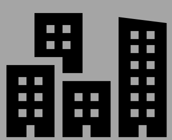
Table 1. Linear economy vs. circular economy (Het Groene Brein, 2017)

Issue	Linear economy	Circular economy
Step plan	Take-Make-Dispose	3R approach: Reduce, Reuse, Recycle
Value chain	Value chain ends with product delivery/ sale to the customer	Value chain can be extended through leasing or maintenance offers
Waste	Yes, after usage the products turn into non-recyclable waste	No, as value of the components remains qualitatively preserved
Lifetime of pure materials	Pure materials are used for one product only	Pure materials are used for several times by retaining the value of the materials.
System boundary	Short term, from purchase to sales	Long term, multiple life cycles
Sustainability	Through eco-efficiency, meaning maximizing economic profit with minimal environmental impact: ➔ postponing the moment of system crash	Through eco-effectivity, meaning radical innovations and system change

Quality of reuse practices	Downcycling (using former product for a lower graded purpose): ➔ reducing the value of materials	Functional reuse, Upcycling or Retain or enhance value of material
Example	Concrete is shredded and used for road filament	Concrete from walls is grinded into grains and used to build a similar wall or a stronger construction element

Table 2 shows a comparison between the current status and the scenario with circular economy in the fields of ‘mobility’, ‘food’ and ‘living space’. Table 2 shows the differences in forms of economy using three examples.

Table 2. Comparison current status vs. scenario with circular economy (Stuchtey, 2016)

	Current status	Scenario with circular economy
	Optimization of every individual system	Optimization of systems and their interdependences
Mobility 	Private top-featured vehicle as dominant means of transport ➔ traffic congestion and depletion of resources	Multi-vehicular mobility, car-sharing, mobility concepts for sustainable transport networks Design focused on longevity
Food 	Greater intensification and specialisation ➔ no rehabilitation of agricultural areas, no nutrient recovery	Closed nutrient cycling Preserved natural capital
Living space 	More efficient supply chain Energy efficiency Increased use of areas	Smart urban planning by using deducible areas in cities Sharing living space and modular buildings

2.9 Present examples of CE implementation

Three examples to show the implementation of CE into business models.

2.9.1 Renault ‘Indra‘ and ‘Choisy-le-Roi‘

The company states: “We are using fewer natural resources in vehicle production by trying whenever possible to replace natural resources with materials that have already been used” (GROUPE RENAULT, 2017). Additionally, the company has two programs to give parts and vehicles a ‘second life’. One program which is ran by Indra, a subsidiary owned jointly with ‘Suez Environnement’, dismantles vehicles before reusing and selling the parts as spare parts. The ‘Choisy-le-Roi’ plant near Paris remanufactures engines, gearboxes, injection pumps and also uses them as standard replacement parts. (GROUPE RENAULT, 2017)

2.9.2 Philips ‘Pay per lux’

The business idea of the Dutch company ‘Philips’ is called ‘pay per lux’ meaning that customers do not pay for the product (e.g. LED lamp) but for the service ‘light’. Clients pay a regular fee to Philips for caring about the lighting service. That includes design, equipment, installation, maintenance and upgrades while still only paying for the consumed light, so to say ‘lux’. By now the ‘pay per lux’ service model is only available for business customers. The long-term plan of the company is to provide the service to any household.

The lighting consists of energy-saving products that can be returned at the end of the contract. Philips production process than reuses the raw materials, optimise the recycling process and therefore reduces waste. (Goldapple, 2016)

2.9.3 Epson ‘PaperLab‘

The machine ‘PaperLab’ can convert waste paper into new paper. Firstly, the waste paper is defibrated, bind and at last formed to a new paper. The production machine can e.g. be used to transform confidential documents into new paper instead of paying for the disposal. (EPSON, 2017)

Figure 8. Epson PaperLab (EPSON, 2016)

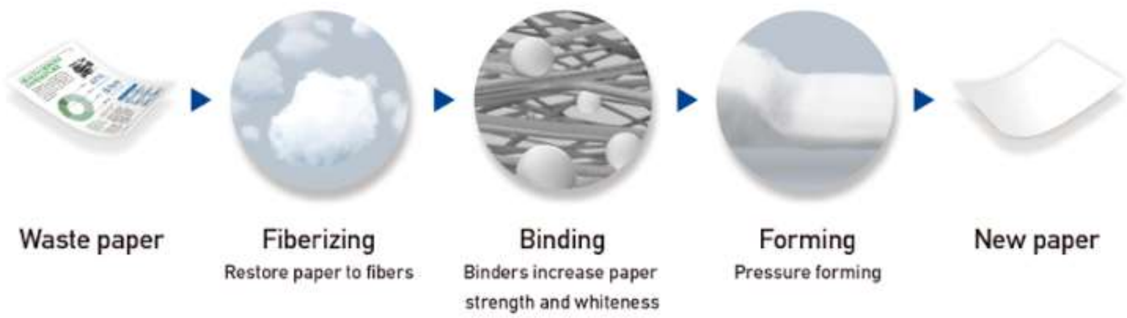


Figure 9. Epson PaperLab (EPSON, 2016)

2.10 Advantages and Disadvantages for companies and customers

This chapter describes the advantages and disadvantages for both companies and customers when switching from a linear model to a circular model.

2.10.1 Advantages

As seen in the previous chapters, the implementation of CE will create several of advantages:

- **Economic growth**: through CE activities which provide more value and lower costs of production through the more efficient uses of inputs. "European GDP could increase as much as 11 % by 2030 and 27 % by 2050, compared with 4 % and 15 % in the current development scenario"; (Ellen Macarthur Foundation, 2015)
- **Increased competitiveness of Europe's industry**: for example, better societal outcomes including an increase of € 3,000 in household income, a reduction in the cost of time lost to congestion by 16 %, and a halving of carbon dioxide emissions compared with current levels; (Ellen Macarthur Foundation, 2015)
- **The creation of jobs**: "In analysis conducted on Denmark, modelling suggested that ten circular economy opportunities could unlock, by 2035, 7.300–13.300 job equivalents, or 0,4 – 0,6 % relative to a 'business as usual' scenario"; (Ellen Macarthur Foundation, 2015)
- **Reduction of environmental impacts**: a 48 % reduction of carbon dioxide emissions by 2030 across mobility, food systems, and the built environment, or 83 % by 2050. A reduction in land use, air, water and noise pollution, release of toxic substances, and climate change; (Ellen Macarthur Foundation, 2015)
- **Preserved natural resources**: trough recycling of waste and the extended product lifetime. Even more so given the existing model of production and consumption and the growing world population. At the current rate of growth and levels of resource intensity we would need three planets' worth of resources by 2050; (Lacy, 2015)
- **Minimising dependency on imports**: Recycling of materials will decrease the vulnerability from importing raw materials; (European Environmet Agency, 2016)
- **Decrease in price levels and volatility**: Recycling gives less demand for new resources and therefore more price stability;

- **Cost savings**: "In the sectors of complex medium-lived products in the EU the annual net material cost savings opportunity amounts to up to USD 630 billion in an advanced circular economy scenario"; (Ellen Macarthur Foundation, 2015)
- **Increased income**: The income of an average European household could increase through the reduced cost of products and services and reduction in congestion costs;
- **Increased value of materials and products**: because of restorative use of resources;
- **Improved working conditions**: An increase in welfare of employees is often demanded in CE practices which involves the use of materials and labour in third world countries; and
- **Innovation**: The benefits of a more innovative economy include higher rates of technological development, improved materials, labour, energy efficiency, and more profit opportunities for companies.
  (Ellen Macarthur Foundation, 2015)

2.10.2 Disadvantages

Apart from the advantages, the implementation of CE it will also bring challenges:

- **New models and patterns**: Fundamental changes throughout the value chain, from product design and production processes to new business models and consumption patterns; (European Environmet Agency, 2016)
- **Frictions from change**: between the existing linear system and the new approaches are bound to arise. These may be perceived as threats by some stakeholders, but as opportunities by others; (European Environmet Agency, 2016)
- **Change of business models**: Remodelling of business models, which requires an organizational and cultural shift; (European Environmet Agency, 2016)
- **Need for more knowledge**: for a transition on aspects such as production structures and functions, consumption dynamics, finance and fiscal mechanisms and technological and social innovations. This is necessary to inform decision making on environmental, social and economic impacts; (Lacy, 2015)
- **Need for technological innovations**: The circular economy necessitates the development of radical new products, technologies and materials. We need to understand on the material level how to deal with stocks, flows of energy and materials; (Lacy, 2015)

- **Possible financial risks**: There is a different financial risk in a circular business models. For instance, the timing of cash flows, creditworthiness of clients and a larger need for working capital; (European Environmet Agency, 2016)
- **Less competitiveness**: Information-sharing along the supply chain can raise questions about information security and competitiveness within companies; and (Ellen Macarthur Foundation, 2015)
- **Design barriers**: The barriers in design technology are:
    - Limited attention for end-of-life-phase in current product designs;
    - Limited availability and quality of recycling material;
    - New challenges to separate the bio- from the techno cycle; and
    - Linear technologies are deeply rooted. (Ellen Macarthur Foundation, 2015)

2.10.3 Government as a market player

In addition to drawing up specific policies, the government can also act as a market player to stimulate the development of circular economy. In this case the government specifically requests circular and sustainable products. (Het Groene Brein, 2017)

2.11 Influencing factors for implementation of CE for SMEs

Given the advantages and disadvantages of the implementation of CE, there are a number of influencing factors that can support or obstruct the adoption of CE. For a circular economy to work it requires both effort of citizens, businesses and government worldwide to adopt a new way of thinking to change production and consumption patterns.

2.11.1 EU government

The European Commission plays an important role in the implementation of CE in Europe.

On 2nd December 2015, the European Commission adopted an ambitious new circular economy package. This package will help European businesses and consumers to make the transition to a stronger and more circular economy, in which resources are used in a more sustainable way. This package included legislative proposals on waste management, with long-term targets to reduce landfilling and increase recycling and reuse. In order to close the loop of product lifecycles, it also included an action plan. This plan needs to support the circular economy in each step of the value chain. From production to consumption, repair and manufacturing, waste management and secondary raw materials that are fed back into the economy.

After the Circular Economy Stakeholder Conference held in Brussels on 9-10 March 2017, the Commission and the EESC jointly launched the European Circular Economy Stakeholder Platform. A platform for gathering knowledge on circular economy and a place for dialogue among stakeholders.

The EU has also been working on an Economy Finance Support Platform with the European Investment Bank (EIB) bringing together investors and innovators. There is been guidance issued to Member States on converting waste to energy. The commission has proposed a targeted improvement of legislation on certain hazardous substances in electrical and electronic equipment.

(European Commission, 2017)

2.11.2 Additional influences

Several additional influences can affect SME's during their implementation of CE.

- **Sustainable Development Goals**: The UN has formulated 17 Sustainable Development Goals (SDG's) that describe targets for all participating countries, leading to a more sustainable world. Target 8 (decent work and economic growth) and target 12 (responsible production and consumption) are strongly related to the achievement of a circular economy. (Het Groene Brein, 2017)
- **Learning from nature (ecomimicry)**: Nature has known a closed, well-functioning system for millions of years. What can we learn from natural cycles, co-dependency, and processes such as growth and decay? (Het Groene Brein, 2017)
- **Practical understanding**: The question 'what does CE means on practical level' is important for businesses and organisations to make a proper transition. This includes more clarity of the terminology. (Het Groene Brein, 2017)
- **Unwillingness among some businesses**: To truly flourish, the circular economy needs to be part of a bigger effort to tackle wasteful consumerism and undemocratic power structures in the global economy. It needs to be geared to the real needs of all people rather than the excessive consumption of a few, and to be underpinned by more cooperative mechanisms rather than controlled by a small number of powerful companies. (The Guardian , 2017)
- **Policies barriers**: Current policies and legislation are generally written in and for a linear economy. They may (unintentionally) hinder the transition to a circular economy. (Het Groene Brein, 2017)
- **Customer adoption**: The adoption of circular practices and products by consumers and society takes effort. Some barriers are lack of knowledge, lack of enthusiasm and a lack of awareness that a transition is necessary and. Two other important barriers are the appreciation for ownership and attractiveness of refurbished and re-used products. (Het Groene Brein, 2017)

3 Introduction to construction industry

The history of the construction industry started from the first signs of human activity and is still visible in the current time. Techniques for describing a building may vary depending on the age and the amount of information available. A lack of written records for ancient buildings means that its description is based entirely on the archaeological recordings and interpretation made by the researchers. The procedure is simpler on recent buildings since there is a lot of material on record: pictures, models and even interviews with those involved in the actual phases of the building (Construction History Society, 2014).

As a matter of fact, the construction industry along with the infrastructure works, compared to other sectors, stand together for the highest resource usage as well as emissions of polluting waste products. The numbers vary depending on the country, but generally one could assume that these sectors obtain a share of 30 % to 50 % in energy consumption and stand for about 40 % of the CO_2 emissions while 15 % to 40 % of its waste ends up as landfilling (Net Balance Foundation, 2017).

3.1 Construction industry definition

The construction industry within the European Union can be defined, in compliance with the International NACE classifications, as the following subsectors:

- Architectural and engineering activities together with related technical consultancy
- Site preparation
- Building of complete constructions or specific parts
- Building installation
- Building completion
- Renting of construction or demolition equipment together with an operator

The construction industry is very labour intense, while having a low productivity over time in comparison with the other manufacturing sectors. Future development in the sector will be characterized by an increased influence of energy savings, resource depletion as well as increased variety of materials and technology. Upcoming land reforms, restructure of the property market, the further growing international market and the lower demand for workers, led by the further automatization, will also play a key role in the further development of the sector. (Methodological Centre for Vocational Education and Training, 2008)

3.2 Current situation of the Finnish construction industry

The Finnish construction industry is characterized by manufacturing construction materials, building constructions, building repairs, construction of roads and waterways. The biggest players in the industry are YIT-Yhtymä Oyj, Skanska Oy, Lemminkäinen Oyj and NCC Finland Oy, with the central federation Rakennusteollisuus RT r.y. representing the entire construction sector (Lindberg, 2008).

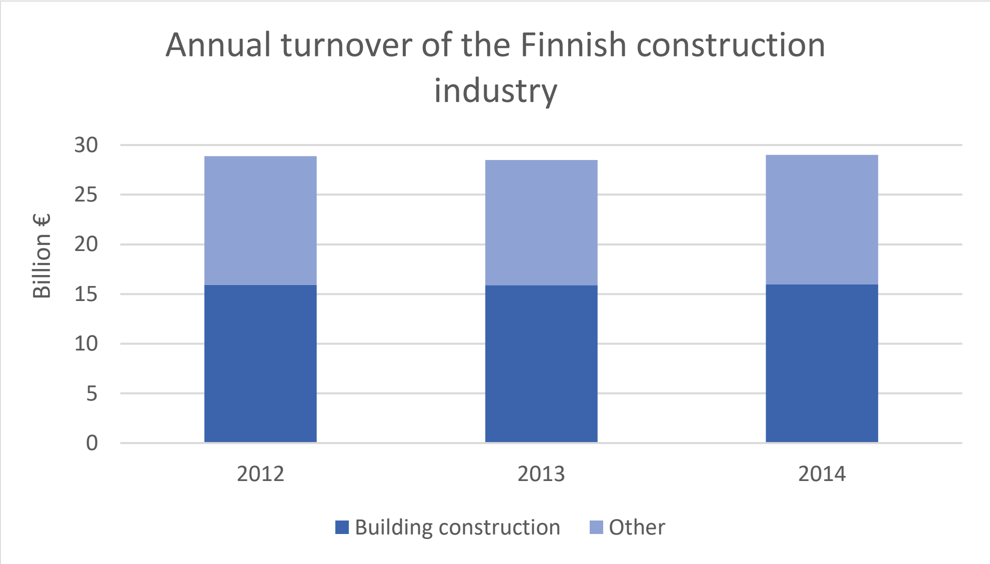


Figure 10. Turnover of the Finnish construction industry

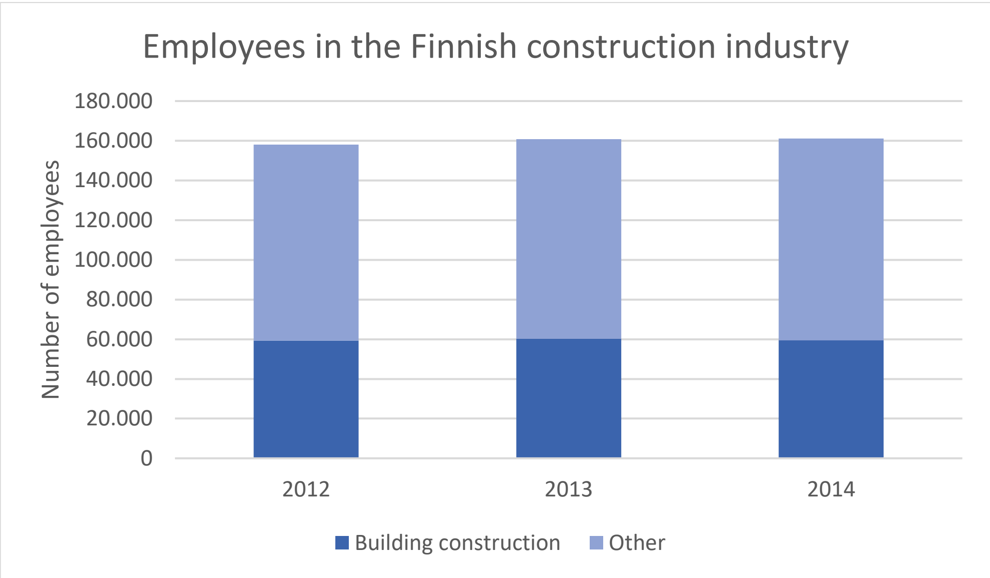


Figure 11. Employees in the Finnish construction industry

The sector has been in a stable situation of neither growth or decline in the past few years, both in turnover and number of employees, as seen in Figure 10 and Figure 11. The turnover, as seen in Figure 10, was almost € 30 billion in 2014 (Statista, 2017a), of which € 16 billion were in the building construction sector (Statista, 2017b). In 2014 the construction industry in Finland had approximately 161.000 employees (see Figure 11) (Statista, 2017c), 59.000 of those allocated in the building construction sector (Statista, 2017d). One can therefor say that roughly one third of the employees stand for half of the turnover in the sector.

In the beginning of 2017 the European Commission published guidelines regarding the implementation of CE in its member states. Shortly after, the Finnish government led by the Prime Minister Juha Sipilä announced their vision of making Finland one of the leading countries in circular economy by 2025. This announcement is believed to be realized through a bigger contribution in the strategic priority of bio economy and clean solutions (Ministry of the Environment, 2017).

The governments' goal is to ensure sustainable economic growth, improve employment and ensure the financing of public services and social security through the implementation of key projects and law reforms. A total of € 1,6 billion has been reserved for these projects, of which € 1 billion is allocated to the main strategic priorities of employment and competitiveness (€ 170 million), knowledge and education (€ 300 million), wellbeing and health (€ 130 million), bio economy and clean solutions (€ 300 million) and digitization, experimentation and deregulation (€ 100 million) (Finnish Government).

3.3 Opportunities

Money makes the world go around. Therefore, innovative technologies are broadly implemented. The advantages of circular economy can be very much characterized in the so called green buildings. The knowledge of the benefits from these green buildings is getting more and more widespread. In general, the benefits can be divided in three areas: environmental, economic and social.

Taking it down to the basics, the environmental benefits of green buildings are a decrease in the greenhouse gas emissions through savings and efficient usage of both energy and resources. Efficiency is a focus as the world is facing a resource depletion. Lower running costs and lower construction costs result in more money for other usages. Also, according to the World Green Building Council based on gathered facts and statistics, lower running costs give the building a higher occupancy rate and therefor an increased propriety value. These economic aspects alone should be able to convince people to invest in green buildings. Apart from the environmental and economic aspect, green buildings care for the health and wellbeing of its occupants. They are proven to give a positive social impact, which in turn leads to a healthier, happier and more productive live for those who work or live in the buildings.

(World Green Building Council, 2016)

3.4 Enablers

Four core enablers are listed for supporting the advance of CE in the construction industry. They answer the questions what, who, how and why supporting circular economy in the construction industry. Those enablers are technological, institutional, internal actions based and the final enabler is the influence by the market.

Hard and soft technologies, knowledge and information categorize the technological enablers. These are the means and opportunities to make changes providing a knowledge base and a technical capacity while answering to the question what.

The government, professional bodies, professional and educational institutions are all part of the institutional enablers. They provide a guidance and stimulation to the environment which can both boosts and enforce changes, answering the question how.

Interests, commitment, policies, management, resources and capabilities are all part of the internal action enablers. These actions provide a strong platform with all the resources and capabilities needed for acting, answering to the question who.

Demand is what controls the available supply and vice versa, so in other words the customer has a strong market influence with its demand affecting the market. Making circular buildings more affordable would incentivize the customers and the industry towards more sustainable buildings. In other words, why should customers follow circular principles - because it is more affordable, and why should the market follow circular principles - because there is a request for it.

(Abidin, et al., 2013)

3.5 Barriers

The same enablers listed in the previous paragraph can also become barriers in case they are not incentivized. A shortage of locally-harvested green technologies can lead to a barrier in the technological aspect of the matter, due to eventually high prices for the imported products. A slow bureaucratically progress and an absence of incentives from the government becomes a major barrier for the institutional aspect. Not prioritizing the matter is an issue out of the internal aspect, while a great low-cost demand is a main barrier both out of the internal aspect and the one of the market (Abidin, et al., 2013).

3.6 Rating tools

There are several different certification schemes for rating buildings that corresponds to a certain requirement. As for the topic of this research the World Green Building Council, a global network supporting green building technology, recognises up to 40 different building rating tools. These different tools are both under the administration of the World Green Building Councils' but also consist of individual organisations. The World Green Building Council points out that each rating tool has a certain usage in a certain area, therefore they do not take sides on considering one overall rating tool.

Among the different rating tools, the most known ones are BREEAM and LEED (World Green Building Council, 2017). Building Research Establishment Environmental Assessment Method, BREEAM, was established year 1990 in the UK and measures the environmental performance of non-domestic buildings. Leadership in Energy and Environmental Design, LEED, is an internationally known green building certification system established year 1993 in the US. They promote sustainable practices in the building industry aiming for an improved performance on the usage of energy, water, general resources, as well as lower the CO_2 emissions and higher the indoor environmental quality. (European Green Office, 2011).

3.7 Dependencies

The construction industry is dependent on a couple of factors. Most of the factors are shared by the rest of the manufacturing industry, but there are a couple of construction industry specific factors (Bankvall, et al., sd). These will be specific in the following numeration:

- Pooled interdependencies of resources such as equipment and locations;
- Sequential interdependencies of steps within the building process; and
- Mutual interdependencies based on a finish start dependency of tasks.

3.8 Supply chain

A supply chain comprehends everything involving the production process of a product from supplier to the client/ customer. Every kind of resource (people, information, goods and activities) will be visualized as a step in the supply chain. This allows for the improvement of the process by streamlining the flow of goods and improving co-operation between different companies. A supply chain can be used for both a linear or circular economy business process, where re-used materials can enter the chain in the same way as new materials.

The construction industry uses in general the following supply chain:

(Koskela & Verhoef) characterized the supply chain in construction as:

- Converging at the construction site where the object is assembled from incoming materials;
- Temporary producing one-off construction projects through repeated reconfiguration of project organizations separated from the design;
- Typical make-to-order supply chain, with every project creating a new product or prototype.

The supply chain for the construction industry deviates from the manufacturing industry due to the following points (Segersteds & Olofsson):

- **One of a kind product**: this requires very high flexibility and is therefore not suited for continued or batch production. It limits the efficiency of the production process;
- **Temporary organisation**: building for example a house requires a lot of different materials as well as a lot of different skills to use to materials. This results in either a construction company with many diversely skilled employees or in outsourcing the jobs. The latter is chosen most often, since it also lowers the risk of failure for both the client and the company; and
- **Site production**: the production of a building generally takes place on site. This means that the production method for building the house has to be flexible and mobile. This makes the use of production lines vary hard, with the solutions being pre-fabricated parts and modular designing for customising.

4 Best practice cases

In order to fulfil the assignment, cases of CE-thinking in the European construction industry were found, and a further research into six European CE buildings was performed. The number of examples was chosen by taking the available time for this project into account. The buildings were selected from a generated list of European CE buildings. The complete list of all the buildings can be on the website: https://thecircleeps.wordpress.com/startseite/ce-in-european-construction-industry/

The general criteria for selecting the buildings were the following:

- Diversity in the type of building (Residential, Office, Private or Public);
- Diversity in the ReSOLVE themes applied in the buildings (Regenerate, Share, Optimise, Loop, Virtualise and Exchange)

Additionally, there are more selection criteria concerning the projects support for the Botnia-Atlantica EU project:

- Related to the wood industry;
- Related to maintenance (since this is an actual subject in the Ostrobothnia region);
- Examples with closed supply chains;
- Buildings close to Finland (or the Netherlands) for visiting;
- Applicable to the Ostrobothnia region (not to complex case)

The six buildings chosen based on the above criteria for further research are both in the field of residential and office buildings:

Residential

- Finch Buildings (Regenerate, Share, Optimise, Loop, Exchange)
- Pluspuu Talot (Regenerate, Share, Optimise, Exchange)
- Villa Asserbo (Regenerate, Optimise, Loop, Virtualise, Exchange)

Office

- De Fire Styrelser (Share, Optimise, Exchange)
- Park 20|20 (Regenerate, Optimise, Loop, Virtualise, Exchange)
- Bionorica Headquarter (Regenerate, Optimise, Loop, Virtualise, Exchange)

4.1 Research topics

The researches have been carried out on all six buildings concerning the following topics:

- **General information**: proving name, location, construction year, architect, manufacturing company, type of building, area, tags from the ReSOLVE framework and a link for further information.
- **Project goals**: giving an insight of which goals were pursued by establishing the building.
- **Supply chain**: pointing out the supply chain and the companies involved.
- **Biological and technical cycle**: explaining the implementation of biological cycles and technical solutions and in detail.
- **Law and incentives**: looking at the legislation and restrictions in the country where the building is situated.
- **Geographical influences**: looking at the environment in the country where the building is situated.
- **Rating and Conclusion**: giving a conclusion about the building based on the ReSOLVE framework.

4.2 Finch Buildings

Finch buildings are modular buildings made by Finch Buildings B.V. (see Figure 12). The company aims to construct high-quality, flexible, comfortable and affordable buildings made from durable and environmentally friendly materials. The buildings, which are made of separate prefabricated modules (see Figure 13), can be transported by road and are suitable for various target groups and locations. The surface area of the modules can be adjusted and due to a flexible utility system and the interior of the modules can also be adjusted to the customer's needs. According to the company the buildings have high energy efficiency and a lifetime of over 100 years (Finch Buildings, 2017). The main material used in the buildings is FSC (Forest Stewardship Council) and/or PEFC (Programme for Endorsement of Forest Certification Schemes) certified wood, and according to the company about 90 % of all materials used in the modules are suitable for reuse. In addition, the total cost of ownership is lower than competitive alternatives over a lifespan of 15 years, according to Joran van Schaik, responsible for the Research & Development at Finch Buildings B.V. (Van Schaik, 2017). An example of how a ground plan for a module looks like can be seen in Figure 14.

FINCH
evolutionary wooden buildings

Figure 12. Logo Finch Buildings B.V.

4.2.1 General information

Figure 13. Finch buildings (Finch Buildings, 2017)

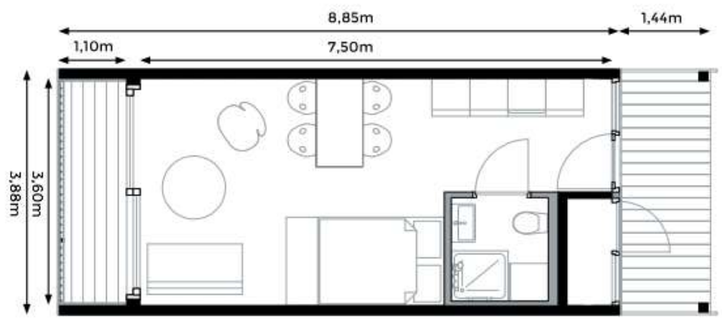


Figure 14. Finch buildings ground plan (Finch Buildings, 2017)

Name:	Finch Buildings
Visiting location:	Amsterdam, the Netherlands
Building locations:	Cornelis Lelylaan, Amsterdam Java-eiland, Amsterdam Sumatrastraat, Leiden
Construction year:	2015 - Cornelis Lelylaan 2016 - Java-eiland 2017 - Sumatrastraat
Client:	Finch Buildings B.V.
Founder & architect:	Jurrian Knijtijzer
Manufacturing companies:	De Groot Vroomshoop Groep Loohuis Groep Timmerfabriek De Mors
Type of building:	Residential building
Area:	Approximately 29 m^2
Tags:	Regenerate, Share, Optimise, Loop and Exchange
Link:	http://www.finchbuildings.com/

4.2.2 Project goals

The aim of Finch Buildings B.V. is to build high-quality, flexible, comfortable and affordable buildings made from durable and environmentally friendly materials. The buildings should serve multiple target group and application, such as a studio, a three-room apartment, an office, a health care department or a hotel. (Finch Buildings, 2017).

4.2.3 Supply chain

To achieve circularity in the supply chain, environmental friendly materials are chosen for the buildings were possible, and during construction and transportation environmental aspects are taken into account. Actions include separated waste disposal, reusable packaging and good communication with the local area as well as its residents. (Finch Buildings, 2016).

The suppliers of Finch Buildings stay involved in the realized products. They want to keep learning from developments in the market and further improve the products. According to Schaik, the suppliers and Finch Buildings B.V. together strive for circularity in the supply chain. (Van Schaik, 2017).

De Groot Vroomshoop Groep

De Groot Vroomshoop Groep (Figure 15) produces the modules for Finch Buildings and is a vital part of the construction company VolkerWessels. De Groot Vroomshoop Groep has more than 85 years of experience, there are approximately 200 professionals employed and the company has a production site area of eight hectares. De Groot Vroomshoop Groep consists of three departments: construction systems, glued wood construction and wood construction. Through close cooperation with this company the product has been designed in detail. (Finch Buildings, 2016).

Figure 15. Logo De Groot Vroomshoop Groep (De Groot Vroomshoop, 2017)

Loohuis Groep

Loohuis (Figure 16) supplies and designs the installation technique for the Finch buildings. The company strives for the quality of living and working through the application of suitable installation technology. They provide solutions from design to realization, as well as maintenance and management of all technical installations in and around the buildings. The company meets all the requirements of innovation, quality and safety standards, while being a certified installer as well as a family enterprise with a history of over 60 years. (Finch Buildings, 2016).

Figure 16. Logo Loohuis Groep (Loohuis, 2017)

Timmerfabriek De Mors

De Mors (Figure 17) produces durable products made out of wood. They are specialized in woodwork and carpentry. Their core activities are the production of frames, windows and doors. De Mors also supplies interiors, unit building and produces sandwich panels. The 'myCUBY' bathrooms, used in the Finch Buildings, are assembled according to a new and sustainable method which is a result of years of experience in prefabricated units and panels. (Finch Buildings, 2016).

Figure 17. Logo Timmerfabriek De Mors (De Mors BV, 2017)

4.2.4 Biological and technical cycles

The following paragraphs will outline achievements that Finch Buildings B.V. accomplished concerning the integration of CE in their buildings, as well as other relevant information.

4.2.4.1 Configuration model

The configuration model of Finch buildings consists of five elements: the hull, exterior, balcony, interior and technical installations.

The hull

The hull is made of large cross-laminated timber (CLT) panels, which serve as a solid construction product due to the bonded single-layer panels (Figure 18). The panels can be screwed together to create different thicknesses, with a minimum of three panels, depending on the thickness needed for the hull. (Finch Buildings, 2016).

Figure 18. Cross-laminated timber (Finch Buildings, 2017)

Due to the standard dimension of the hull the modules are stackable, switchable and easy to connect to each other. Also, vertical connections can be made which add more possibilities to the layout. If the hull (Figure 19) is made with 140 mm thick walls, up to five modules can be stacked on top of each other. It is also possible to construct the hull with 100 mm thick walls, which allows up to two modules to be stacked on to each other. The solid wood walls also function as a fire separation and meet all sound requirements. (Finch Buildings, 2017).

Figure 19. Hull (Finch Buildings, 2016)

The exterior

The applied facade coating is made of western red cedar and is used vertically. However, are multiple cladding options such as aluminium, brick or durable wood (Figure 21). In case of the wooden facade cladding, it is attached to the prefabricated wall insulation module (Figure 21). Finch Buildings usually carry the frames out in meranti wood with triple glazing. For the layout of the porch sliding doors are used, but conventional doors and windows are among the options too.

Figure 21. Exterior (Finch Buildings, 2016)

The Finch module is supplied usually with a fixed gallery of Azobé. The gallery on the ground floor can be left out, making it possible to get direct access to the street.

(Finch Buildings, 2016).

Figure 20. Exterior cladding (Finch Buildings, 2017)

The module can be equipped with a 3,8 m² balcony (Figure 22). Access to the balcony is provided by large glass sliding doors. The balcony is trimmed with the same facade cover as the outside of the module. (Finch Buildings, 2016).

Figure 22. Balcony (Finch Buildings, 2016)

The interior

The interior consists of the bathroom module, the kitchen and the floor (Figure 23). Due to the modular construction system and the smart floor in which all pipes are laid, the kitchen and bathroom can be placed throughout the module.

Figure 23. Interior (Finch Buildings, 2016)

The functional interior (bathroom and kitchen) is supplied as a prefabricated product and installed at the factory. However, this can be easily adjusted afterwards. By default, Finch Buildings install a four kitchen blocks with cabinets.

For the bathroom there are two size options. The bathroom module is optimized and circularly designed. The wet cell can be placed in its entirety and removed in parts. The standard interior finish of the bathroom is white, but also coloured foils can be chosen.

A separate toilet belongs to the possibilities, as well as the installation of interior walls to create rooms. The floor is covered with linoleum flooring, but also a bamboo or wood finish are possbile. (Finch Buildings, 2016).

The technical installations

The technical system of the module consists out of installations for heating, hot water and ventilation, but also the electrical closet, sewage and drainage systems (Figure 24). The smart floor allows improvements in technology and electronics in the future.

Figure 24. Technique (Finch Buildings, 2016)

Due to the design of the technical area, the rooms can be vertically connected to each other. The design has largely taken into account fire separation, noise and ease of use. When designing the meter box, extra space was left for a home battery.

The modules can be delivered as Zero-energy buildings NOM, which means they are self-sufficient in terms of energy. A heat pump can be chosen which provides heating for the rooms (radiators or underfloor heating) and the hot water. Also, solar panels can be installed on the roof.

(Finch Buildings, 2016).

4.2.4.2 Flexibility

In this chapter, the flexibility of the buildings will be described.

Transportation

The modules of Finch Buildings are easy to transport by truck and delivered in one piece, fully equipped, making them ready to move in immediately. As it can be seen in Figure 25, the modules can be picked up and placed using a crane. (Finch Buildings, 2017).

Figure 25. Placement of the module (Finch Buildings, 2017)

Multifunctionality

As said before, the Finch Buildings modules are suitable for multiple applications to serve multiple target groups and locations, as an example in Figure 26.

Figure 26. Holiday homes at sea (Finch Buildings, 2016)

This is possible because the modules themselves are 'plug play', which makes them easy to be assembled and relocated. Application options include student and family homes, elderly homes, offices and homes for the recreation sector. Finch Buildings has worked out four variants based on one type of module, the ´studio´ (Figure 27), living, working, care and recreation. (Finch Buildings, 2016).

Figure 27. Studio (Finch Buildings, 2016)

If the customer wishes, an extra half or a whole module can be added as an extension (Figure 28). These adjustments can even be made years after the original building was placed. (Finch Buildings, 2016).

Figure 28. Finch 2 (Finch Buildings, 2016)

4.2.4.3 Sustainability

Finch Buildings took several measures to realise a sustainable building as described below.

Circular design

The modules are designed according to circular principles. This means that more than 90 % of all materials used in the module are suitable for reuse and therefore help to close material circuits. Almost all materials are natural and emission-free**.** Furthermore, Finch buildings produce barely any waste due to prefabricating.

The base of the building, which consists of the walls, floor and ceiling, is made of massive CLT (Cross-Laminated Timber). CLT as a product is highly suitable for reuse and the glues used are environmentally friendly (Van Schaik, 2017). The panels are machined as little as possible, which creates large untapped solid wood panels after the manufacturing operation. Furthermore, the panels are interconnected by means of screws, which results in a high rate of reuse and residual value at the end of the operating period. Another example of circularity are the walls of the bathroom that are fitted with Velcro fasteners to the hull to easily remove them. (Finch Buildings, 2016).

Wood

For the Finch buildings, wood is chosen as a main construction material. All wood types used for the construction of the Finch module are FSC and/or PEFC certified. Wood as a building material is chosen because it is renewable and it is the only building material that stores CO_2 instead of producing it. One module can store up to 20 tonnes of CO_2. In addition, a Finch module hardly uses steel and doesn’t use concrete, both materials that would emit CO_2. Also, for every three trees used five trees are replanted. As a result, a Finch module is 60 tonnes carbon negative. (Finch Buildings, 2016).

Energy efficiency

By using high-quality construction and insulation materials, Finch buildings modules have a low energy requirement and primary energy consumption. For example, wood is a good insulator, which reduces energy demand. This can be further reduced by applying advanced installation technologies and the use of solar panels. The module is 'all-electric': which implies using electricity for all home appliances (heating, cooking and hot water supply). An 'all-electric' building can be fully powered by green energy, which means that the module does not emit CO_2. For lighting, energy-efficient LED luminaires can be used for both indoor and outdoor lighting. The balcony of the module functions as a passive awning, which keeps the house cooler in the summer by creating shadings and warmer in the winter by letting sunlight directly enter through the windows. (Finch Buildings, 2016).

Durability

The hull is made from wood, a solid foundation that can be used for longer than 50 years as stated in the Dutch Building Regulations. According to the construction company, the hull can last for over 100 years if well protected from weather,

The building is made resistant to several factors like fire, excessive rain and typhoons. For example, the CLT forms a layer of char when exposed to fire, which is heat insulating and protects the wood underneath. This is better than more conventional constructions, such as concrete, that require more fire protection measures.

CLT is protected from rain and other external moistures damages thanks to the instalment of a rain screen. However, the wood is exposed to moisture from the indoor environment, but this is normally a controlled environment with a set temperature and humidity that does not result in higher moisture content in the wooden panels.

The wood has a low risk of being attacked by termites, due to a protecting foil wrapped around it which is only visible from the inside of the building. This also provides for a long-term duration of the visual aspect.

The buildings have a typhoon resilient design, as it can withstand relatively high wind speeds and after a typhoon it can be brought back to its original state relatively easy.

(Finch Buildings, 2016) (Finch Buildings, 2017).

4.2.4.4 Human well-being

An important aspect of the Finch Buildings modules is the healthy living environment, which can be seen through the choice of materials. Wood has a positive effect on human health, psyche and well-being, for example by lowering stress. It is moisture regulating, as it absorbs moisture from the environment if there is an excess of it, and releases moisture as soon as a room becomes too dry. Thanks to this balanced humidity there is a decreased risk of infections, bacteria and fungi. Wood also feels warm, unlike walls of stone, because of its low heat conductivity. Besides, a lot of thought has been put into the design of the Finch buildings to realize an attractive form that appeals to the customer and the people who live in and around it. Finch Buildings B.V. describe their style as 'warm modernism' (Figure 29). Finally, the buildings are not exposed to toxic radon gas. This gas that is emitted by radium increases the risk of lung cancer when inhaled. Good ventilation can reduce the risk of accumulation in closed areas. (Finch Buildings, 2016).

Figure 29. Interior (Finch Buildings, 2017)

4.2.5 Economics viability

After a lifespan of 15 years, the modules are cheaper and more durable than competitive alternatives. This is mainly due to the fact that the critical parameters are beneficial to the total cost of ownership (TCO) calculation. These critical parameters consist of high quality, relatively cheap and guaranteed high residual value materials, as well as adaptability of the building, low relocation costs, excellent energy efficiency scores and limited maintenance costs. (Van Schaik, 2017) (De Architect, 2017)

The displacement costs are unprecedentedly low in modular construction. Finch buildings do not have to be disassembled when relocated or located and the building can be placed or lifted with one hoist. (Finch Buildings, 2016).

The extra investment to make Zero-energy buildings is currently not easily profitable. (Van Schaik, 2017)

4.2.6 Influencing factors

The following chapter describes several influencing factors in the execution of Finch buildings.

4.2.6.1 Legislation influences

Some legislation barriers for the implementation of CE in the Finch buildings are:

1. The Finch modules have to comply with the strict permanent requirements of the Dutch Building Decision 2012, allowing them to be used for permanent or multiple temporary operating periods. (Finch Buildings, 2016)
2. Finch buildings do not qualify for the EPV (Energy Performance Fee) compensation. Schaik says:" The buildings can meet all the requirements of the EPV except one, the maximum energy consumption per m^2. This is due to the very small surface area of the unit which results in a much higher energy demand per m^2 compared to a 100 m^2 house." (Van Schaik, 2017)

4.2.6.2 Customer and society influences

Different parties are not yet prepared to pay for a high-quality product that last long, despite all positive reviews available. According to Schaik, customers value sustainability and circularity significantly in the procurement phase, but ultimately, corporations and developers still choose the non-circular alternative, even if they know the Finch Buildings are eventually less costly based on the TCO. (Van Schaik, 2017)

Finch Buildings B.V. are trying to find partners that want to form a coalition to represent the interests of sustainable spaces, both for permanent or temporary alternatives. (Van Schaik, 2017)

4.2.7 Rating and conclusion

According to the ReSOLVE framework by the Ellen MacArthur Foundation, the modules by Finch Buildings B.V. cover the following aspects of circular economy:

Regenerate	About 90 % of all materials used in the module are suitable for reuse and emission-free. The wood types used for the construction of the Finch module are FSC and/or PEFC certified and the use of wood makes the buildings a CO_2 buffer. For every three trees used, five trees are planted back.
Share	The building will last for over 100 years when well protected from weather influences.
Optimise	The buildings produce almost no waste through smart design and prefabricating. A high level of modularity and flexibility in the buildings is achieved, which makes the buildings suitable for multiple applications, target groups and locations. For example, the surface area and the interior can be adjusted, due to the modular construction systems and a smart floor. Finch modules have a low energy performance by default and are easy and cheap to transport by road.
Loop	Non-permanent connection techniques in the modules make the rate of reuse high. The company is working together with its suppliers to achieve circularity in the supply chain.
Exchange	The modules are 'all-electric' which makes them suitable to operate entirely on green energy. The balcony also provides better energy performance through the passive blinds. A heat pump and solar panels on the roof are optional.

Influencing factors such as legislation and customers affect the realisation of the project. For example, customers value sustainability and circularity significantly in the procurement phase, but ultimately corporations and developers still choose the non-circular alternative at the end, even when the TCO is lower over a period of 15 years. To solve this problem Finch Buildings is trying to find partners that want to form a coalition to represent the interests of sustainable (permanent or temporary) spaces. Additionally, from a legislative point of view, there is an EPV (Energy Performance Fee) compensation for energy saving buildings which cannot be met by the Finch buildings. One rule about the maximum energy demand per m^2 cannot be applied to the Finch buildings because it does not consider that small spaces by default have a higher energy consumption compared to large spaces.

Information on the influence of other legislations on the realisation of the project has not been found and some questions still remain, such as: which parties are involved in the final phase of the building? How did Finch Buildings gather their know-how? In addition, more detailed information about the technical aspects of the buildings might be useful for further use in the Botnia-Atlantica project.

Finch Buildings B.V. does not have neither BREEAM or LEED certificates.

4.3 Pluspuu Talot

The company focused on in this chapter is named Pluspuu Talot, a Helsinki-based studio founded in late 2009. It is formally known as Pluspuu Oy and it offers architectural services with house packages as their main product (Fonecta, 2017).

Their house packages consist of carefully designed log houses, made using a durable material and in various designs to make them suitable both as homes and holiday residences. Furthermore, they offer also small saunas.

Traditionally, log houses are built using single trunks as well as laminated logs. The particularity of Pluspuu Talot is that they offer the latest in Finnish log technology, a non-settling log system, combined with cross laminated timber panels and tailored structural solutions in order to match the customers' needs.

As Pluspuu Talot is a design studio they collaborate with the Tampere-based Ollikaisen Hirsirakenne Oy, a construction company with a long history in log-constructions, to carry out the construction of the residences from paper to actual life.

Circular economy comes in place as Pluspuu Talot follows the principles of sustainable development in quality, aiming to offer high quality rather than low price, and choice of material, as wood is a durable, renewable and recyclable material. All residences are hand built on site, aiming to minimize the waste of materials.

(Pluspuu, 2017a)

Figure 30. The company's logo (Pluspuu, 2017a)

4.3.1 General information

Figure 31. Log chalet Iniö 100 (Pluspuu, 2017b)

Company name:	Pluspuu Oy
Location:	Helsinki, Finland
Founded:	2009
CEO:	Markku Miettinen
Manufacturer:	Ollikaisen Hirsirakenne Oy
Location:	Tampere, Finland
Type of buildings:	Residential and holiday residences
Area:	20-126 m^2
Tags:	Regenerate, Share, Optimise, Exchange
Link:	http://www.pluspuu.fi/en/

4.3.2 Project goals

As noticeable under the previous heading, Pluspuu Talot is a newly started company, with less than ten years on the market, that offers modern log houses of high quality and using sustainable materials as well as innovative techniques. Concerning vision and goals, the following is what the company states on their website:

> “Pluspuu offers a wide range of modern log houses for quality-conscious customers. Pluspuu houses transcend our conventional notions of traditional log houses. The elegant architectural design, the mitred corner joints and narrow seams between logs all contribute to the image of a light and modern wooden building. Logs walls are durable and long-lasting and offer a healthy indoor environment” (Pluspuu, 2017c).

During the research phase the company was contacted for clarifications about certain aspects of their circularity, such as maximising the value at the end of their useful life trough upcycling, recycling, maintaining and upgrading, as well as possible future improvements. The company stated that they were busy and could not answer any questions. This leads to the conclusion that the research is based only on the available information online, since crucial information by the company, that would possibly have changed the outcome of the research, might be missing.

> “Reliable quality and unique design with more than 35 years of experience” (Ollikaisen Hirsirakenne, 2017a) is the slogan of Ollikaisen Hirsirakenne.

The construction company firmly points out the quality and experience in the field as well as an overall corporate mission of green values, using wood as their primary material, and waste reduction programs.

4.3.3 Supply chain

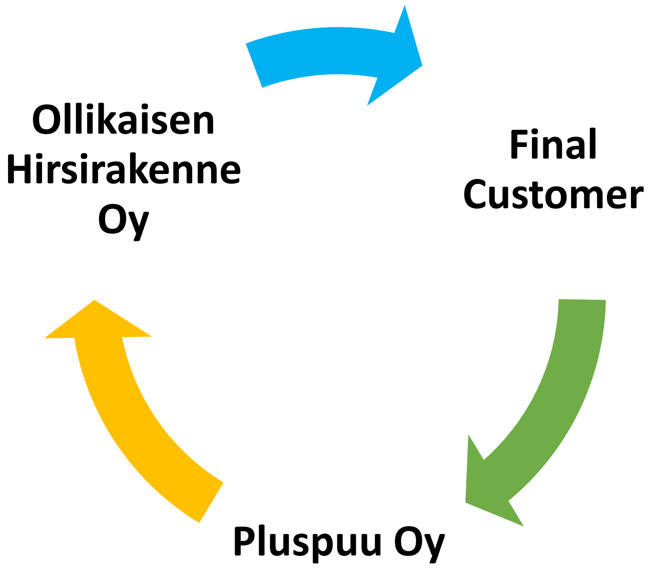


Figure 32. Simplified structure of the supply chain

As shown in Figure 32, the supply chain can be described as the following:

- **Final customer**: Places the order, follows up the progress
- **Pluspuu Oy**: Designs, plans, sales
- **Ollikaisen Hirsirakenne Oy**: Chooses the materials, produces, executes the construction

The company did not answer the question of the existence of an actual loop after sales in between the three entities. The possibility of such a loop is not to be neglected, as the company is newly established, and its already constructed products are still 'young'. However, further research is needed to clarify the roles in the supply chain.

As already mentioned in the introduction chapter, Pluspuu Talot takes the services of Ollikaisen Hirsirakenne for constructing the structures. They are said to be a company with superior knowledge in both woodworking as well as log constructions, granting for a final product of high quality (Pluspuu, 2017a). The logs used are carefully selected in the local area near the construction company to minimize the carbon footprint from the transport, then sawn, dried and made into their final shape by a subcontractor of Ollikaisen Hirsirakenne.

Through the recognition of current ecological problems, they are aiming to evolve their production into a more sustainable direction, without their operations drawing unnecessarily energy from the environment. “Our goal is to ensure that future generations can enjoy the same rich and pure nature [that we have] today” (Ollikaisen Hirsirakenne, 2017a).

The production line of Ollikaisen Hirsirakenne takes advantage of a newly introduced CAD-CAM system by the German Hundegger Maschinenbau GmbH, a leading manufacturer in the field of eco-friendly woodworking machinery, to work on the wood. The CAD-CAM system, meaning Computer-Aided Design/Computer-Aided Manufacturing, is a CNC software that allows for an optimized material usage while keeping stable and predictable results in the production. (Ollikaisen Hirsirakenne, 2017a)

4.3.4 Biological and technical cycles

“Wood is the only building material whose amount is constantly increasing [trough replanting]. By using wood, the consumption of non-renewable materials can be reduced and/or completely avoided” (Wood Products, n.d.a). Wood buildings are known for their durability as we can find log houses, that are still in use, dating back to the 15th century. Furthermore, the use of logs removes the need of additional synthetic insulation material, as the logs insulates when thick enough (Ollikaisen Hirsirakenne, 2017a). Today’s advanced adhesive compound allows wood to breathe naturally, as massive logs do, maintaining a comfortable indoor climate and humidity (Ollikaisen Hirsirakenne, 2017b).

Pluspuu Talot offers different solutions and technologies in order to meet the customer’s needs, reaching new grounds in the market for timber house constructions. Further information about the implementation of renewable energy sources, such as geothermal energy or solar panels, could not be found, and comments on the question were not given by the company upon contact.

Stated on their website, the following wood construction options are offered to the customers:

- **Non-settling log:** made of spruce or pine, differs from traditional laminated logs by having vertical lamellas in the middle part of the log, shown in Figure 33. This removes the need of post-construction adjustments of various parts since wood swells and shrinks during normal circumstances. Additionally, this technology removes the need of outer wall supports, which makes it more suitable for urban environments.

Figure 33. Non-settling log (Pluspuu, 2017d)

- **CLT solid wood panels:** commonly found in multi-storey timber buildings, the technology of Cross Laminated Timber solid wood panels is particularly useful in ceilings and floors since they remove the need of supporting braces, shown in Figure 34.

Figure 34. CLT solid wood panel (Pluspuu, 2017d)

- **Solid logs:** obtained from thermal dried pine logs, shown in Figure 35. This traditional material for building log houses is referred by Pluspuu to be the most ecological construction material. This because there is no need for an extensive manufacturing process as well as the use of synthetic materials. The logs are likely to crack over time, which is a natural development that only affects the esthetical aspect of the building.

Figure 35. Solid logs (Pluspuu, 2017d)

- **Laminated logs**: preferably used in log house walls by several manufacturers, this material is less likely to show sights of cracks and residues over time. Lamella logs with no signs of horizontal joints on visible surfaces, shown in Figure 36, are offered to the customers by Pluspuu Talot.

Figure 36. Laminated logs (Pluspuu, 2017d)

- **Mitred corner joints:** offered aside with the traditional full-scribe joints, mitred corner joints, shown in Figure 37, remove the need of overlapping joints due to its thickness, weight and sealing performance. This makes them more suitable for the construction of log houses in urban environments.

Figure 37. Mitred corner joints (Pluspuu, 2017d)

(Pluspuu, 2017d)

4.3.5 Influencing factors

The following chapter describes several influencing factors in the execution of Pluspuu Talot.

4.3.5.1 Legislations

The Finnish Government imposes legislation on the construction industry to ensure that the available information by the designers and developers is made in a reliable and comparable way, promoting the sales both in the Finnish market as well as abroad. Finland follows the EU Construction Products Regulation, applied in all the member states of the European Union. The basic requirements for construction products are related to resistance, stability, safety, hygiene, health, environmental impact, sustainability, accessibility, noise protection, heat and energy savings. These requirements also action as a foundation for the ETA, European Technical Approvals, a uniformed standard in the European Union. (Ministry of the Environment, 2016)

Housing design

Under this heading in the Finnish National Building Code one can find specific information about the housing design. It is stated that the design and construction of residential spaces are to be ensured to be done in a way that fits the purpose, while being pleasant and comfortable. The design needs to be developed according to the requirements of the residents, while being ready for various future changes in their needs and conditions. There is a demand to show that both environmental and natural factors are taken into consideration when choosing the location of the building, its arrangement with the different spaces as well as other topics associated to the housing design (Ministry of the Environment, 2017b).

The National Building code of Finland

The Finnish building procedure is specified in the Land Use and Building Act. More detailed, one can find here the overall guidelines for building, relating technical requirements, applying for a building permit and the construction supervision carried out by the authorities. The relating technical requirements section for the buildings address for example strength, stability, fire safety, accessibility and energy efficiency. There is also information available about the decision making in issues regarding guidelines in the use and maintenance procedures.

Traditionally, the regulations apply only to newly erected buildings, while for renovated and alternated buildings the regulations only apply when extended measures are taken - if no other specific regulation occurs. As the code is constantly being revised, the decrees are changing to better clarify in which class they will be applicable. (Ministry of the Environment, 2017b)

According to the Ministry of the Environment, approximately 40 % of the country's energy consumption is traceable to buildings. There are currently energy legislations promoting efficiency and renewable energy sources to meet the European Energy Efficiency Directives, as well as Finland's own goals of reducing the country's energy consumption and carbon footprint. (Ministry of the Environment, 2017c)

The decrees on building are going to be revised during the year 2018, with the objective to make the regulation of buildings more comprehensible, the application of it more consistent and predictable, and reduce the existing regulations to make it easily understandable (Ministry of the Environment, 2017b).

4.3.5.2 Geography

Finland has the highest percentage of forest area within the EU, covering three quarters of the country's soil (Finnish Forest Association, 2016a). Wood made from the Finnish forestry has a good status due to its quality and sustainable development value (Ollikaisen Hirsirakenne, 2017a). This means that geographically Pluspuu Talot and its manufacturing company Ollikaisen Hirsirakenne are both located in a suitable location for the kind of solution they offer.

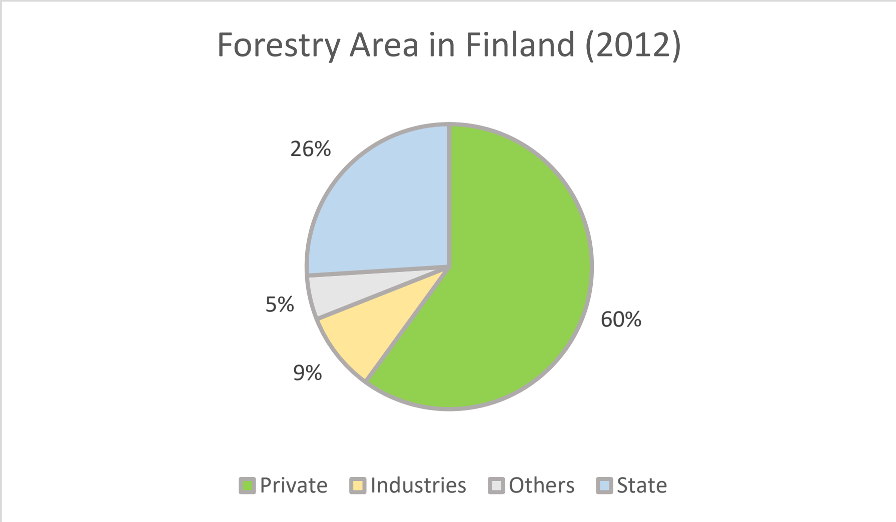


Figure 38. Share of the forestry area in Finland (Finnish Forest Association, 2016b)

By 2012, most of the forestry area in Finland, approximately 60 %, was owned by private individuals and families. Normally a property consists of several owners sharing it. As noticeable in Figure 38, private industries held a 9 % share, other entities a 5 % share while the state held the resting 26 % of the Finnish productive forests land. The state-owned forests consisted of almost 50 % by protected forests, mostly situated in the northern part of the country. (Finnish Forest Association, 2016b)

"Finland is one of the best areas in the world for tree growth. It belongs to the cold climatic belt in which sub-zero winters alternate with warm summers. The summer season lasts only 100 days, during which the trees grow. The short growing season means slow growth, which may last 60-120 years. […] The result is a hard, tough and straight-grained timber with low tension and few internal cracks. The low-resinous, evenly patterned Finnish wood is first-class material for many purposes." (Wood Products, n.d.b)

The characteristics of the Finnish wood are a high resistance to various weather variations as well as being a natural breathing building material (Ollikaisen Hirsirakenne, 2017a). Since the country is located in the boreal coniferous zone, only a few tree species have been able to adapt due to the acid-poor soil. Most of the forests are a mix of several species, with approximately 50 % consisting of pine and the resting half dominated by spruce, downy birch and silver birch (Finnish Forest Association, 2016a).

The Finnish productive forestland grows more than its harvested, which creates opportunities to diversify the usage of wood. However, harvesting opportunities are not fully taken advantage of, which might lead to a shortage of wood in the market, as well as the need to import the material, mainly from the neighbouring country Russia. (Finnish Forest Industries, 2017).

4.3.6 Rating and Conclusion

In line with the ReSOLVE framework created by the Ellen MacArthur Foundation, the following conclusions were drawn. Pluspuu Talot and its manufacturing company Ollikaisen Hirsirakenne cover the following four aspects of circular economy:

Regenerate Use of renewable and biodegradable materials, logs and wood, for their buildings.

Share Efficient design built to last. Logs are not permanently attached and easy to replace.

Optimise Simple jointing method, rapid building time, self-insulating logs and less waste in the production.

Loop Not yet discovered if aspects of remanufacturing, refurbishment, recycling are offered.

Virtualise No outspoken aspects of dematerialisation were found.

Exchange The use of new technologies such as non-settling logs and the CLT panels.

Pluspuu Talot achieved certificates from Tehty Suomessa (translated: Made in Finland), WWF Ystäväyritys 2017 (translated: WWF Friendly Company 2017) and is also a member of the Green Building Council Finland (Pluspuu, 2017a). Their manufacturing company Ollikaisen Hirsirakenne is awarded the Luotettava Kumppani (translated: Reliable Partner) and AAA highest credit rating by Bisnode (Ollikaisen Hirsirakenne, 2017a). However, both companies have neither LEED or BREEAM certificates at the moment and further information about future plans of achieving those certificated were not given.

4.3.6.1 Conclusion

Pluspuu Talot is a newly founded company that uses a local manufacturing company and as well as local products. They offer high quality, innovative products, that varies from small saunas up to fully suitable residences in a variety of options in order to meet the customer's demand.

Their line of products is all based on wood, a renewable material that offers characteristics such as insulation, ventilation and durability. The material is a natural choice for Pluspuu Talot and its manufacturing company Ollikaisen Hirsirakenne, as both companies are located in Finland, the European country with the highest percentage of forests.

Finland promotes energy efficiency and renewable energy sources, while also produces quality timber with a good reputation worldwide. The country promotes a building ethic that is reliable and comparable according to the EU Construction Products Regulation. Since there is a higher growth of the wood resources compared to the usage, Finland could enforce more incentives in order to boost the use of this renewable energy sources. After going through how possible legislation could affect the company, there was not found any particular one that would either promote or hinder Pluspuu Talot or neither its manufacturing company Ollikaisen Hirsirakenne. Still it remains unclear if Pluspuu Talot follows the Ecodesign Directive (2009/125/EC) and the Energy Labelling Directive (2010/30/EU).

Pluspuu Talot has some aspects of circularity, but since the lack of information and their unwillingness to answer questions, further statements about their actual circularity, their way of working and possible future development cannot be given at the moment.

4.4 Villa Asserbo

Villa Asserbo is a wooden residential house designed to be easy to produce, build, maintain and disassemble. The residence has been made from different segments, which all can be carried by just two persons. Each segment is created by a technique called ‘Wood 3D printing’, where a digital file can be uploaded into a CNC machine to create the different shaped parts. Combining all milled parts will create the segment, which is then assembled into a house using non-permanent methods.

Most materials are recyclable and energy efficient techniques are implemented to keep the environmental impact to a minimum. The cladding (outside wooden structure) is made of Nordic spruce and local veneer.

4.4.1 General information

Figure 39. Front Villa Asserbo (Eentileen, 2012)

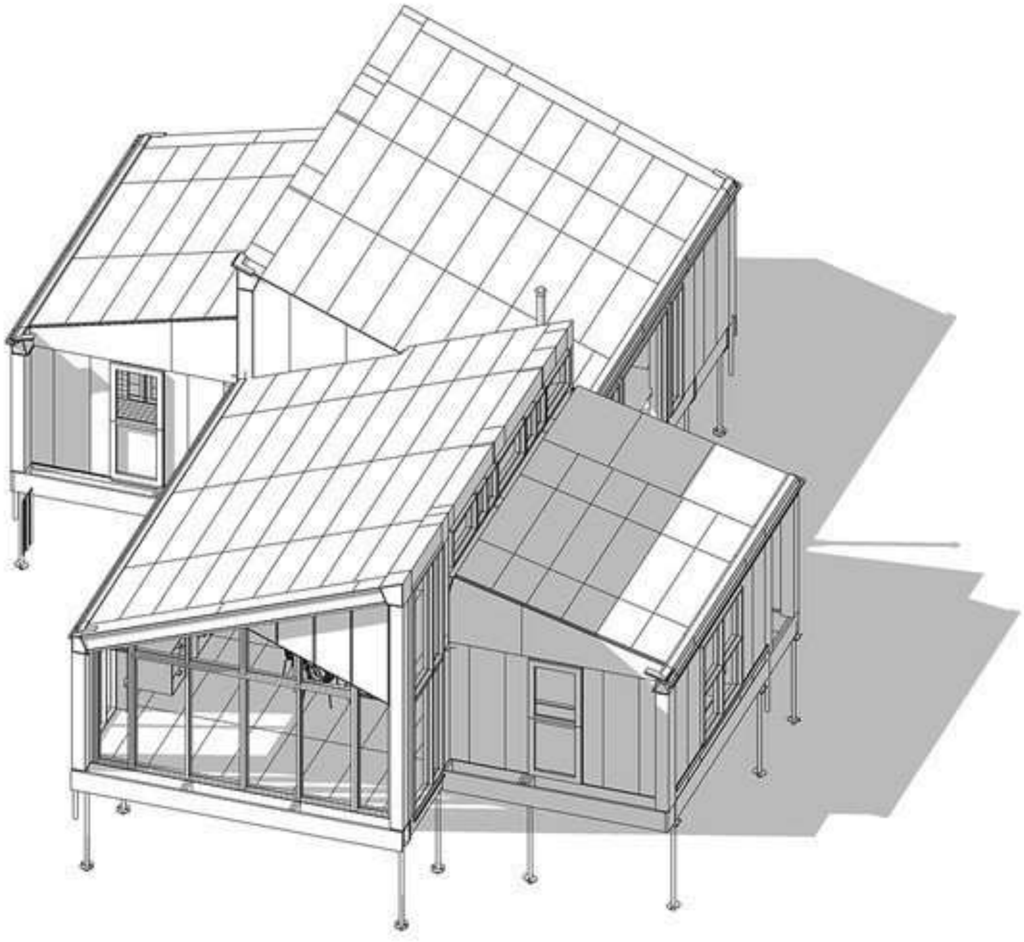


Figure 40. 3D model Villa Asserbo (Eentileen, 2012)

Location/ country:	Asserbo, Nordsjælland, Denmark
Construction year:	2011/ 2012
Architect(s):	Frederik Agdrup & Nicholas Bjørndal (Company: Eentileen, located in Kobenhavn, Denmark)
Manufacturer:	Facit Homes, located in London, Great Britain
Type of building:	Residential house
Area:	125 m^2
Tags (Resolve):	Regenerate, Optimise, Loop, Virtualise, Exchange

4.4.2 Project goals

The architects Nicholas Bjørndal and Frederik Agdrup, Facit homes and the customers had several goals for this project. The main goal is a house with the smallest environmental footprint as possible.

“We take the entire life cycle and all aspects of this into consideration – from the making of the house, to the habitation of the house and in the end the deconstruction and recycling of the house. this means our overall footprint is one of the lowest on the market.” stated by Nicholas Bjørndal to digital magazine Designboom (Designboom, 2013).

This should make it “the most sustainable house on the market,” according to Frederik Agdrup. (ASME, 2012).

The second main goal for this building was the capability to build the house with two persons and without heavy equipment.

“Another dogma for this project has been: no component of the construction is heavier than two men are able to carry it and the house can be built without the use of cranes or heavy machinery. This dogma does not only address the simplicity and innovative approach to designing for assembly, but gives way for several other perspectives on how to approach the global market. It is a highly adaptable system which is easily implemented in regions with limited resources. For example, improvement of housing conditions of 3rd world countries or recovery plans for regions hit by natural disasters.” stated by Frederik Agdrup to Designboom (Designboom, 2013).

Low energy consumption and the use of modular building components made from a 3D model with a CNC machine was also a goal which the builders achieved. The building is energy efficient, took six weeks to build and can be easily dismantled and recycled. Modularity in construction and buildings has great potential in transitioning to a circular economy, and this building could over time be a successful example.

4.4.3 Supply chain

Villa Asserbo is a small and compact house, which is designed to be built anywhere with a CNC machine nearby. Secondly, the building is designed to be 100 % recyclable through the use of sustainable materials such as wood, glass and steel. The aim is to have minimum impact on the environment when used and even when built.

This all results in a limited amount and size of supply chains. Also, since the villa is planned to be built on demand, big supply chains are not in place because of this low volume production.

The building uses several components/materials from manufacturers, such as WISA Plywood (Building material), Superwood (Cladding), Warmcell (Fibre isolation), Kronetag (Olivine roofing) and NKT fasteners (connections). All these materials are made to be recycled, but no recycle partners except for WISA plywood are known. WISA plywood is willing to take the waste wood leftover from production back, and recycle it to make new plywood (UPM, 2011).

More information about the specific materials used and new technologies can be found in the next chapter ‘Biological and technical cycles’.

4.4.4 Biological and technical cycles

Villa Asserbo has several interesting solutions to namely reduce its impact on the environment during building and usage. The noteworthy solutions are: modular segments made of 100 % recyclable wood, 100 % recycled fibre insulation, regenerative roof lining, and non-permanent foundation.

4.4.4.1 Modular segments

Figure 41. Modular segments and building process (Eentileen, 2012)

Villa Asserbo is fully digitally designed, with modular segments and building, as shown in Figure 41. Four types of segments are used, namely ‘wall, roof, floor and header’ types (ASME, 2012). These segments are created by using a CNC machine, which uses sliced 3D models to create G-code which then guides the machine. The CNC machine is fed multiple sheets sequentially to improve production speed.

This stacking of sheets can be interpreted as printing (adding layer after layer), which would make this process 3D wood printing. However, this process is not additive (adds material), but subtractive (removes material) due to milling. The amount of waste from milling is however at a minimum, through usage of the high precision CNC machine and the return policy on waste wood with the plywood supplier (UPM, 2011).

4.4.4.2 Building material

The goal for Villa Asserbo is to be 100 % recyclable. This is achieved by using wood as the main building material. The foundations, the segments and the cladding are all made of sustainable wood with the FSC certificate.

The main building material is WISA spruce plywood, shown in Figure 43, which besides a FSC certification also received a PEFC (sustainable foresting) certification (WISA plywood, 2017). The wood used for the cladding are the SW4 boards from the company Superwood (Superwood, 2017), shown in Figure 42. The company Superwood has received the EU environmental award for being one of Europe’s most environmentally friendly companies (Superwood, 2017).

Figure 42. SW4 boards as cladding (Superwood, 2017)

Figure 43. WISA spruce plywood (Superwood, 2017)

4.4.4.3 Insulation

The insulation of the building is blown cellulose fibres from the company Warmcel, shown in Figure 44. These fibres are made from 100 % recycled newspapers. The newspapers are collected from offices, schools, overruns from printing companies and kerbside collections. The manufacturing process from newspaper to fibre uses very little energy which combined with the material choice gives Warmcel an extremely low GWP (Global warming potential) of 0,106 kg CO_2/kg . Average GWP for commonly used insulation is 1,2 kg CO_2/kg for mineral insulation and 3,0 for SPF (Spray Polyurethane Foam) (Buildinggreen, 2010). GWP means the overall influence of the insulation on the planet by comparing CO_2 produced by production of the material against the CO_2 savings from using it.

Figure 44. Warmcel insulation fibres (Warmcel, 2017)

4.4.4.4 Roofing

The roofing of the building is made out of the material Olivine (iron-magnesium silicate) provided by the company Kronetag. The DERBICOLOR Olivine roofing, shown in Figure 45 uses the material Olivine to neutralize CO_2 when it rains. The rain will bring the CO_2 in contact with the Olivine to create a residue made out of sand (silicon dioxide) and magnesium carbonate, which are both harmless to the environment (Derbigum, 2017).

Figure 45. DERBICOLOR FR Olivine roofing (Derbigum, 2017)

4.4.4.5 Foundation

The foundation of Villa Asserbo is made of 28 steel helical micro piles, installed by Facit homes. The screw piles are expected to be from the company ABC Anchors, since a similar project to Villa Asserbo, built in September 2012 by Facit Homes, was featured in Grand Designs (ABC anchors, 2012).

The used piles are presumably the 60R conical screw piles from ABC Anchors, shown in Figure 46, which allow for easy placement and removal. This means no permanent structures are required for a stable foundation of the villa.

Figure 46. 60R conical screw piles from ABC Anchors (ABC anchors, 2012)

4.4.5 Influencing factors

The following chapter describes several influencing factors in the execution of Villa Asserbo.

4.4.5.1 Legislation

The legislation for buildings may have an impact on the ease of implementation of CE. Therefore local, regional and national legislation will be researched for possible influencing factors.

The legislation in Denmark applies to both Villa Asserbo and De Fire Styrelser. Therefore, this chapter will be split up into general building legislations and a conclusion with the influences of these legislations on the building. The general building legislations will only be added in the Villa Asserbo best practice case.

General legislation

Denmark has the Danish building regulations (BR10, BR15 and BR20). BR10 first appeared in 2010, BR15 in 2015, BR20 will be enforced in 2020. The regulations target residential and commercial sectors, specifically energy consumption.

These building regulations aim to reduce total greenhouse gas emissions by 40 % compared to Denmark in 1990 (Federane, 2014). BR20 aims for a reduction of 75 % compared to 2006, and additionally, Denmark aims to have a 100 % renewable sourced energy and transport system by 2050 (StateofGreen, 2017). Every building regulation has specific requirements for maximum energy consumption and losses true transmission, conduction and radiation. These requirements can be seen in Figure 47.

	Class 2010	Class 2015	Class 2020
Maximum energy demand/year (residential) HFS in the building's heated floor space in m^2	52.5 kWh/m2 + 1650 kWh/ HFS	30 kWh/m2 + 1000 kWh/ HFS	20 kWh/m^2
Maximum energy demand/year (non-residential)[1] HFS in building's heated floor space in m^2	71.3 kWh/m^2 + 1650 kWh/ HFS	41 kWh/m^2 + 1000 kWh/ HFS	25 kWh/m^2
Max. air leakage/second (test pressure 50 Pa)	1.5 l/m2	1.0 l/m2	0.5 l/m2
Max. design transmission loss[2], single-storey	5 W/m^2	4 W/m^2	3.7 W/m^2
Min. energy gain[3] through windows/glazed walls	-33 kWh/m^2year	-17 kWh/m^2year	0 kWh/m^2year

[1] includes demand for lighting

[2] Average heat loss through 1m^2 of the non-transparent parts of the building envelope at 20°C inside temperature and -12 °C outside.

[3] Solar heat gain minus heat loss through 1 m^2 of window (facing south-east) during a standard Danish winter.

Figure 47. Requirements BR10, BR15 & BR20 (Federane, 2014)

Energy consumption for residential buildings will include (according to BR20): "heating, domestic hot water, ventilation, electricity for operating the building (fans, pumps, etc.) and potential penalty for overheating" (Wittchen & Kragh, 2016). Non-residential buildings will have a fixed value of 25 kWh per m^2 which also included lighting (Federane, 2014).

These regulations met certain difficulties during their implementations such as a lack of interest or a lack of knowledge from the targeted sectors. Also, the potential cost savings might be dwarfed by other potential cost savings within the building or company and therefore lack strong incentive for investment. (Federane, 2014). Statistics however show the reduction of energy consumption matching (delayed) the building regulations, shown in Figure 48.

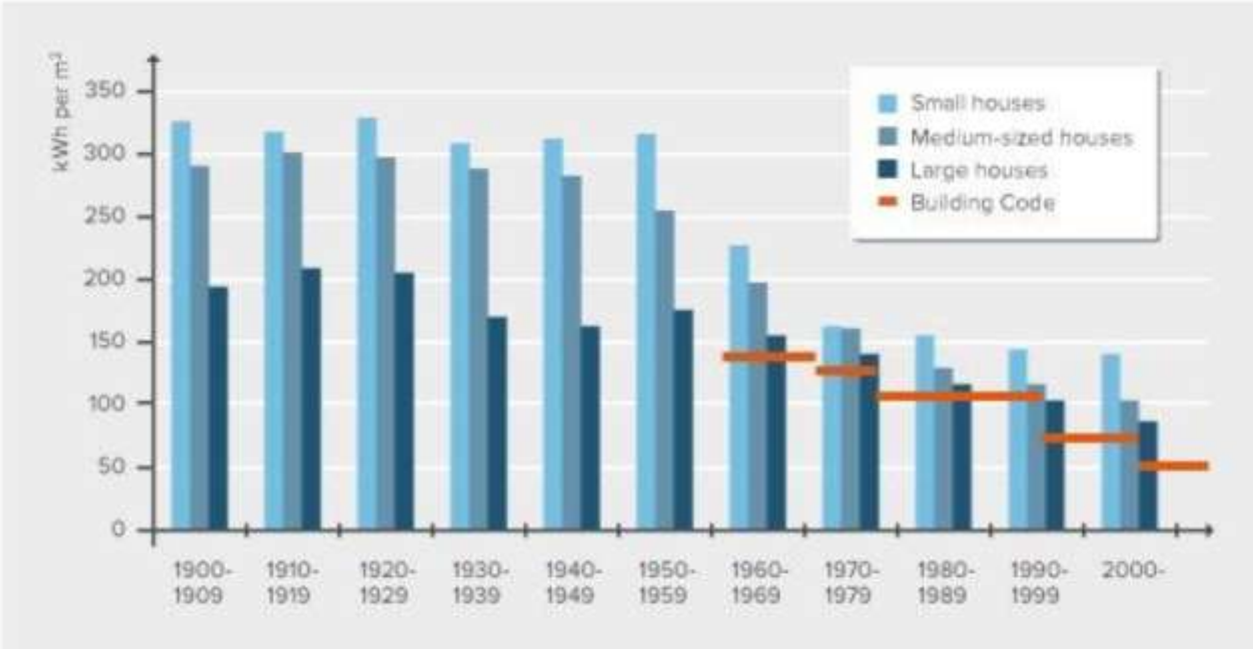


Figure 48. Energy consumption compared to building code requirements (IEA, 2008)

The building regulations include:

- proper usage of the building and its materials;
    - protection against collapses, pests and radon particle has to be implemented besides safety for loads and health;
- dimensioning structures to withstand normal static and dynamic loads;
- designing foundations safe enough to withstand frost and dynamic loads;
- selection of materials to resist conditions of the climate;
    - including moisture sensitive materials, to prevent mold;
    - using quality assurance procedure to guarantee optimal quality of the materials;
- usage of materials with moisture build up;
- building tents smaller than 50 m^2.

(Trafik-, Bygge- og Boligstyrelsen, 2017)

The building regulations contain a number of specific rules/guidelines for moisture/water control. Preventive measures must be applied concerning water damage to structural parts and possible health issues to occupant true condensation, outside water and moisture, groundwater, snow, melt water and general wet area's (bathroom, utility rooms and toilets). (Trafik-, Bygge- og Boligstyrelsen, 2017).

The EU also provides guidelines for designing, constructing and maintaining buildings, which are implemented into the building regulations. The most important norms for buildings in Denmark are:

- DS/EN 1990 Basis of structural constructions;
- DS/EN 1991 Densities, self-weight and imposed loads for buildings;
- DS/EN 1991-1-2 Fire load;
- DS/EN 1991-1-4 Wind load;
- DS/EN 1991-1-5 Thermal load;
- DS/EN 1991-1-7 Accidental actions;
- DS/EN 1995-1-1 General rules and rules for buildings;
- DS/EN 1995-1-2 Timber structures, fire design.
- DS/EN 1993-1 Steel structures
    - DS/EN 1993-1-1 Steel structures, general rules for buildings;
    - DS/EN 1993-1-2 Steel structures, fire dimensioning;
    - DS/EN 1993-1-3 Steel structures, additional rules for cold-formed elements and cladding;
    - DS/EN 1993-1-4 Steel structures, additional rules for stainless steel;
    - DS/EN 1993-1-5 Steel structures, plate construction;
    - DS/EN 1993-1-6 Steel structures, strength and stability of shell structures;
    - DS/EN 1993-1-7 Steel structures, strength and stability under transverse load;
    - DS/EN 1993-1-8 Steel structures, collections;
    - DS/EN 1993-1-9 Steel structures, fatigue;
    - DS/EN 1993-1-10 Steel structure, Material toughness and through-thickness properties.

(Trafik-, Bygge- og Boligstyrelsen, 2017)

No information on differences between regional, local and national legislation can be found. The tasks on regional and local level are enforcing, providing support and were possible adapting the regulations. This differs from national level, where the regulations are created and changed. (ECOtech, 2016).

The legislations in Denmark have several influences on Villa Asserbo. Firstly, building with wood is difficult in Denmark due to the regulations on moisture and water damage. Wood is more susceptible which means it is harder to meet the set requirements for moisture compared to more permanent materials such as steel, bricks and concrete.

Secondly, energy consumption regulations are consistently increasing. These regulations can work as a stimulant to improve the efficiency of a building. It can also increase the need for new and more efficient technological solutions, which might fit the current linear market model better than a circular one.

Lastly, the building needs to be designed for a minimum life span of 20+ years. The life span can be reached through durable materials or by maintenance. Material science shows that highly efficient materials are more expensive and in general have a shorter life span with the same amount of maintenance. Circular economy entails upkeep of the efficiency of a building through maintenance and refurbishment, which will be harder and more expensive when these materials need to be designed for optimal efficiency and set life span. Therefore, a medium will have to be found in the materials’ lifespan and the efficiency, which is not optimal.

4.4.5.2 Geographical influences

Villa Asserbo is located in Asserbo, Nordsjælland in Denmark. Nordsjælland is one of the three big islands, along with Funen and Vendsyssel-thy in Denmark. Nordsjælland is positioned in the east part of Denmark, close to Sweden.

4.4.5.2.1 Physical geography

Physical geography contains information about the natural environment. This includes among other things: oceanography, hydrology, geomorphology, climatology and biography (Wiki, 2017). This chapter will contain the most important factors for buildings, namely the climate and the typography.

Climate

The Nordic countries cover around 3,5 million km^2 and have a very large variety in climates. Denmark has, with its relative southern location, a moderate climate. This climate is also caused due to the high number of waterbodies around Denmark. Denmark is enclosed by the Atlantic Ocean in the west and the Baltic Sea in the east. The Atlantic Ocean with its Gulf Stream brings warm ocean currents from the coast of Florida towards the West Nordic countries.

This results in mild winters and cool summers, with temperatures between -5°C and +30°C. Consequently, little snow cover during winters and relative cool summer are common. This reduces the need for specific building requirements, such as snow retention and guard systems or UV protection windows and high airflow cooling systems. This neutral climate with little temperature fluctuation allows for a highly insulated building where cooling and heating can be kept to a minimum.

Typography

The land in Denmark is in general flat. This makes it easy for building and transport as well as cultivation of the ground. 11 % of the Denmark's area is covered by forest for a total of 4860 km^2, with 69 % of this located on the mainland of Denmark and the remaining 31 % on the islands. Near Asserbo, in the Nordsjælland, is the Gribskov forest located with an area of 55.00 km^2 (Wiki, 2017). Asserbo is located less then 5 km away from the Danish straits, which creates a slightly salty environment (30 parts per 1000) which has to be taken into account when building (Britannica, 1998).

4.4.5.2.2 Human geography

Human geography contains information about the human environment, with includes several aspects such as human, political, cultural, social and economic ones. The most important aspects for building are the economic, development and transportation geography.

Economy

The economy of Denmark shows a 1,2 % growth each year, with an unemployment rate of 6,3 % (heritage, 2017). This places Denmark 14 in the EU rank list for GDP (gross domestic product) (International montary fund, 2016). Denmark has one of the lowest poverty rates in EU in 2014 with a ratio of 0,05 on a population of 5,6 million (OECD, 2014). The average income per working inhabitant is € 40,000, which places Denmark among the top 5 of the highest incomes in the EU (Wiki, 2015). Denmark can therefore be considered a well-developed and prosperous country. Consequently, this cannot be considered a negative influence on investments into circular economy.

Transportation

Denmark is a country with a good transportation system, where most parts of the country can be easily reached. Denmark has been promoting the usage of bicycles, public transport and walking over the usage of a car, which has resulted in a low rate of car usage of 29 % in 2015 (State of green, 2015). Thus, Denmark can be considered to have an advanced and clean mobility and which has little to no effect on the building process of this building.

4.4.6 Rating and conclusion

The building is rated using the ReSOLVE framework, from the Ellen MacArthur Foundation, to conclude which aspects of CE are covered in this building.

Regenerate One of main goals for Villa Asserbo was having a small footprint on its environment. This has been achieved through the use of recyclable materials, such as FSC certified wood, steel removable screw piles as foundation and olivine roofing.

Share Villa Asserbo has used, like most buildings, maintenance to prolong its lifespan and maintain its efficiency. The modular design allows for (slightly) easier upgradability compared to conventional buildings.

Optimise Waste of materials during the construction process and low energy consumption are achieved by accurate building through the use of a high precision CNC machine.

Loop Most of the building materials in Villa Asserbo are meant to be recycled and re-used in either a similar building or down-cycled into other uses.

Virtualise The building plans for Villa Asserbo are fully digital, which removes the need for physical plans and documents.

Exchange The new production technology in this building is the 3D wood printing, which uses a CNC machine to precisely mill all sections for the modular segments and can be combined with on-site production.

Villa Asserbo was set out to become an environmentally friendly building where every facet of the building has been optimised. Impact during production has been reduced through the use of 3D wood printing with an on-site CNC machine. The modular design allows for little waste and removes the need for heavy equipment. The modular building segments also allow for efficient and easily adjustable and upgradable buildings, which can also be disassembled easier.

The screw pile foundation removed the need for a solid permanent foundation and makes it possible reduce the environmental impact after the building has been dismantled. All building materials are recyclable which further reduces its overall impact on the environment.

Villa Asserbo is the first commercial modular 3D wood printed building in the world, and shows the possibilities from this promising concept. This concept of a 3D wood printed building allows for more modular and customizable designs, while 3D printing with other materials opens even more possibilities. Supply chain and re-use sharing is not applied to this building, which could be an opportunity to make this building even more suited for a circular economy.

More detailed research has also shown the influences from geography and legislations on the building. Denmark has a very favourable environment and climate to build this specific building, and is economically in a good position to move forward to a more circular economy. The legislations in place both harm and stimulate building with new materials, since the moisture prevention laws are strict and make building with wood difficult. Efficiency regulations do stimulate/ force investments into more efficient buildings. No information could be found on official sustainability ratings.

4.5 De Fire Styrelser

'De Fire Styrelser', official name being Nexus CPH, is built to be the hub for the Danish traffic council, Danish road directorate, Rail Net Denmark and the DEA (Danish Energy Agency). The building is designed to be flexible, future-proof and provide a healthy working environment.

Besides offering working space for the before mentioned authorities, there are also green walkways, a café, a restaurant, a service centre and a conference and education centre in the building. Light and an abundance of glass allow for a warm and comfortable environment improving the experience for its occupants.

(Arkitema, 2014).

4.5.1 General information

Figure 49. Exterior 'De Fire Styrelser' (Arkitema, 2014)

Figure 50. Interior 'De Fire Styrelser' (Arkitema, 2014)

Figure 51. Progress building (A.Enggaard, 2015)

Name:	Nexus CPH
Location/ country:	Kalvebod Brygge, Copenhagen, Nordsjælland, Denmark.
Construction Year:	2014
Architect:	Arkitema Architects, located in Copenhagen, Denmark
Manufacturer:	MOE, located in Copenhagen, Denmark
Contractor:	Caverion, headquarters located in Helsinki, Finland
Type of building:	Office
Area:	43.000 m^2
Tags (Resolve):	Share, Optimise, Exchange

4.5.2 Project goals

De Fire Styrelser was commissioned by the Danish property agency with the one of the requirements being: a new office building as a PPP (Private Public Partnership) project (Bygningsstyrelsen, 2017).

This form of cooperation includes design, construction, operation, maintenance and financing as tasks for the contractor (Wiki, 2017). Efficiency of the building in a PPP project is a main priority for the contractor, because a higher efficiency equals the opportunity for higher profits. This leads to the usage of more durable and energy efficient materials, compared to traditional buildings. Therefore, initial costs will be higher and should be earned back over the complete lifecycle of the building. This leads to: investments into efficiency improving solutions, flexible design and easier to maintain solutions.

Another requirement for the building was to provide a healthy working environment, flexible enough to change to the needs of its occupants and the possibility to be easily upgraded in the future. Energy efficiency was another goal to keep running costs and environmental impact as low as possible. An impressive design would also allow it to be a visual marker when entering or leaving Copenhagen, given its location near one of the mayor entrance roads of the city in Kalvebod Brygge.

The selection of the contractor was based on the lowest possible offered price, which met all set requirements and meets as many optional requirements as possible. The building is currently being constructed, so besides the proposed plans little to no additional information is available. These plans however indicate that most requirements will be met.

4.5.3 Supply chain

The supply chain for De Fire Styrelser is designed as a PPP project. The user will have an agreement with the contractor for a set price for usage of the building. This form of contracts is relatively new, and information is scarce regarding the PPP agreement for this building. However, known is the certain risk the contractor takes by agreeing to a PPP contract. Therefore, an extensive SWOT analysis is useful to outline the threats within the project, for example pre-contact risks, buildings risks (building site, design, construction and commissioning risk), financial risks, operating risks, user based risks, legislative risks and building specific risks (AusAID, 2009).

The contractor for the De Fire Styrelser is the company Caverion (former YIT and ABB electric), which specializes in designing, installing and servicing of energy efficiency technical solutions for buildings, infrastructure, industrial plants, marine and offshore. Caverion provides electrical, plumbing, ventilation, cooling, security and automation installations (Dagensbyggeri, 2015). The agreement to build and maintain the technical installations is for 25 years, with sustainable solutions being the main focus to have the lowest possible LCC (Total Lifecycle Cost) for the building (Dagensbyggeri, 2015).

Subcontracting is the responsibility of the contractor, which includes the architectural firm Arkitema for designing the building and engineering firm MOE.

4.5.4 Biological and technical cycles

The technical and biological cycle of a product encloses every step from production to disassembly. The eventual goal is a biological cycle where the material is harvested, manufactured into a product, being used for as long as possible and then returned to the biosphere with minimum damage. The technical cycle should provide solutions which prolong the life of a product to the maximum and reduces damage from usage to its environment.

De Fire Styrelser focuses predominantly on durability, flexibility and efficiency, due to the PPP contract which is explained in the chapter Project goals. This focus is clearly visible in the construction method of the building. The materials are also planned to be recycled after deconstruction, to reduce environmental impact and costs (KEA, 2016).

The building is constructed to have load bearing facades, several supporting concrete cores, stairs and elevators to support the floors and roof. This allows for an open workspace due to the lack of vertical supports. It also allows for easy upgradability of the building, since the floor is not load bearing.

The floors and the roof are made of hollow 400 mm thick pre-stressed slabs, shown in Figure 52, which are loosely positioned in between the facades, merging points of the wings of the buildings and cores. This allows for slight movement to counter heat influences and movement within the structure. (DEPA, 2015).

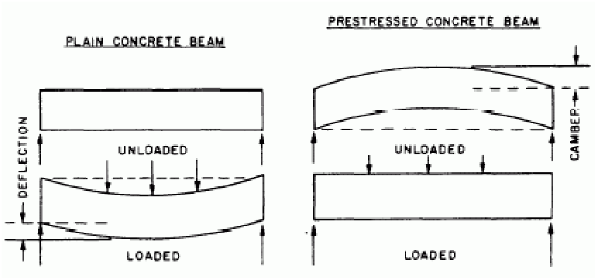


Figure 52. Non-stressed vs Pre-stressed slab (Wellsconcrete, 2017)

Efficiency is increased through the use of solar panels, which lowers the total energy consumption of the building (Nordicpropertynews, 2016). The windows are made of wood, aluminium and composite to offer a renewable, low maintenance and well insulated solutions. Other possible solutions (inclusion of solutions cannot be proven, since the building is still in construction) are rainwater collection, low energy consuming light sources and a green roof (Molio, 2015). The building meets the Danish BR20 regulations, and can therefore be classified as a low energy building (Bygningsstyrelsen, 2017).

The last noteworthy feature of the building is the inclusion of smart technical installations from Caverion, which uses digital and automated solutions. These solutions provide an efficient and optimized installation for both consumption and durability.

4.5.5 Influencing factors

The following chapter describes the influencing factors in the execution of De Fire Styrelser.

4.5.5.1 Legislation

The legislation for this building may have an impact on the ease of implementation of CE. Therefore local, regional and national legislation will be researched for possible influencing factors. This specific building is located in Copenhagen, Nordsjælland, Denmark, similar to Villa Asserbo. The general legislation of Denmark can be found in chapter Villa Asserbo ‘Legislation’.

The legislations in Denmark have several influences on De Fire Styrelser. One of them is the energy consumption regulations proposed in the building regulations. These regulations can both work as a stimulant or a deterrent, since the building needs to be updated to meet the new regulations every five years. De Fire Styrelser was set out to meet the BR20 regulations, and is therefore very efficient.

A second influence is the large number of guidelines for designing steel structures in buildings. Added to this are extra rules for occupant safety, fire safety, technical installation requirements and minimum strength requirements which all heavily influence the building process of an office building in general. These regulations could impair circular solutions, which could make it a deterrent.

Lastly, a building is designed with a certain lifespan in mind, which can be achieved through durable materials and/ or maintenance. The balance between costs, durability and efficiency can be proven to be difficult. It either requires large amounts of technology and resources or compromises to achieve the set life span at maximum efficiency as circular economy (Optimise) would entail.

4.5.5.2 Geographical influences

De Fire Styrelser is located in Copenhagen, in Denmark. This consequently means the influences from geography will be the same as for Villa Asserbo.

4.5.6 Conclusion and ratings

The building is rated using the ReSOLVE framework, from the Ellen MacArthur Foundation, to conclude which aspects of CE are covered.

Regenerate	De Fire Styrelser makes use of solar panels, incorporates a park in the building and has green roofs.
Share	The building has been designed to be upgraded and flexible though the use of loadbearing facades and supporting cores which allows for open workspaces and removable floors.
Optimise	Efficiency is one of the main focus points due to the PPP (Public Private Partnership) contract. This leads to low-energy technical installations with digital controlling for maximum efficiency.
Loop	Most of the building materials are meant to be recycled, to regain a large amount of the initial investment back after deconstruction.
Virtualise	This building has no new specific virtualize aspects. (The building is designed and tested digitally for energy usage and different loads. This practice is however commonly used in new buildings.
Exchange	PPP agreements are uncommon, but have a great potential to create a circular business model.

De Fire Styrelser was designed with the PPP agreement in mind. This means the use of efficient systems and materials to reduce the LCC as much as possible, since the responsibility for the functioning of the entire building will be for the contractor Caverion. The lower LCC outweigh the higher initial costs, which means the PPP agreement acted as a stimulant to investments in energy efficient systems, such as solar panels, energy efficient windows and rainwater collection. The building complies to the building regulations BR20 and can therefore be considered a low-energy building.

Flexibility and upgradability are also important aspects of this building, since they prolong the effective life of the building and allow for higher occupation rates. The load-bearing facades and supporting cores allow for open workspaces and relatively easy to replace/ move floors. These open workspaces should allow for a more healthy and inspiring working atmosphere.

More detailed research has also shown the influences from geography and legislations on the building. Denmark has a very mild environment and climate which makes it easy to build, combined with its good economical position allows Denmark to move forward to a more circular economy. The building is one of many circular projects from the government and initiatives to create a more sustainable environment in Denmark. The Danish legislations both harm and stimulate building with new materials, where efficiency regulations stimulate/ force investments into more efficient solutions and buildings. No information could be found on official sustainability ratings.

4.6 Park 20|20

Park 20|20 C.V. is a business park (Figure 53) located in Hoofddorp, close to Amsterdam Schiphol International Airport, in the Netherlands. “It is the first fully operational cradle to cradle work environment” according to park 2020 (Park 20|20, 2010), developed by Delta Development Group, VolkerWessels and Reggeborgh Groep (Park 20|20, 2010). The business park incorporates different circular solutions such as buildings that are designed for disassembly, the use of solar panels, heat and cold storage, wind orientation and ventilation, a “closed loop” water-management system on site, green roofs and nature sites. The main focus of this project, besides its cradle to cradle aspect, is the human well-being of its occupants. It aims to be an “inspirational environment that stimulates the creativity and effectiveness of employees by creating safe and healthy places for work and recreation.” (William McDonough + Partners, 2010).

Al buildings are BREEAM or LEED certificated as can be seen in Figure 54, which also shows the EPC value of some building. The EPC value describes the energy consumption per square meter of a building per year in kW / m². (Hebbes, 2017)

A project called ‘Valley’, developed by the same groups as Park 20|20, has started nearby with the goal of becoming “the first circular business development hub in the world” (Valley, 2015).

4.6.1 General information

Figure 53. Park 20|20 (William McDonough + Partners, 2010)

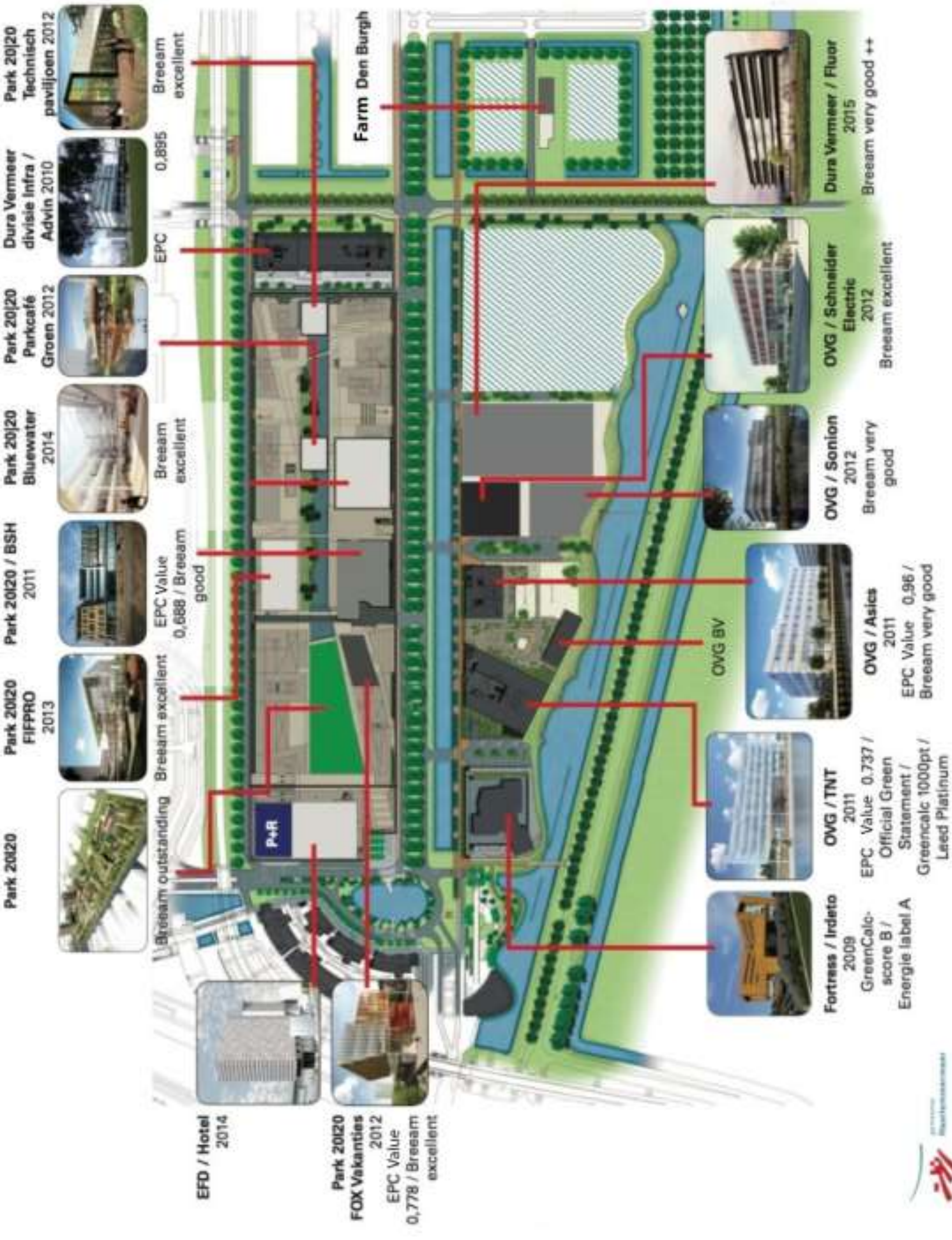


Figure 54. Buildings in Park 20|20 and their certificates (Van Der Meer, 2015)

Name:	Park 20|20 C.V.
Location:	Hoofddorp, Netherlands
Construction year:	Started 2009. Expected to be completed in 2017
Client:	Delta Development Group
Master planning:	William McDonough + Partners
Landscape architect:	Nelson Byrd Woltz
Project executors:	VolkerWessels
	Reggeborgh Group
	Delta Development Group
Type of building:	Office Building
Area:	114.000 m^2
ReSOLVE tags:	Regenerate, Share, Optimise, Loop, Virtualise, Exchange
Link:	http://www.park2020.com/

4.6.2 Project goals

The developers of Park 20|20 are aiming to become the first fully Cradle to Cradle (C2C) Business Park in the Netherlands (William McDonough + Partners, 2010). Apart from that, they wish to design a work space that encourages employees' creativity and performance, leading to increased productivity and less absence. Their method to become C2C is by leasing products and returning them after use, which is an effective economic model to lower the purchase value of a building and to implement the latest innovations. (Park 20|20, 2010) The goals of Park 20|20 include increasing the surrounding area's economic viability, attracting and retaining workers, supporting connectivity with nearby communities and reducing the region's traffic congestion by transit-oriented development.

To support environmental sustainability, the developers aim to increase biodiversity and regional natural connectivity, use renewable and passive energy strategies, eliminate waste, and extend the lifetime and residual value of buildings. (Asla, 2010) The C2C concept aids many of these goals by making designs for disassembly, material passports, using biodegradable materials, and reusing and recycling materials. (William McDonough + Partners, 2010)

As the developers of Park 20|20 want to stay on top of latest sustainable developments, they cooperate with other organizations, NGOs and universities in an innovation platform. The goals of this platform are to further increase renewable energy use, save more water by increased cleaning and filtration, and increase the amount of materials that can be recycled or reused. (William McDonough + Partners, 2010).

4.6.3 Supply chain

Park 20|20 was founded by three partners: Delta Development Group, VolkerWessels and Reggeborgh Group. This collaboration has previously proved successful in the re-development of the former Fokker industrial facility into the sustainable Fokker Logistics Park located in Schiphol, Netherlands. (William McDonough + Partners, 2010)

The architects responsible for the masterplan of Park 20|20 are William McDonough + Partners, together with the Dutch architectural firm N3O. William McDonough is the author of the book 'Cradle to Cradle: remaking the way we make things'. (Park 20|20, 2010).

Site and architectural design of Phase I commenced in 2009 and is utilizing C2C protocol for material specification. Construction of the first building began March 2010. (Asla, 2010)

Delta Development Group

Delta Development Group (Figure 55) is an independent, internationally operating property developer. Since 2012, Delta's office is located at Park 20|20. Delta is a pioneer in the field of sustainable and Cradle to Cradle developments. The company has invested a lot of energy and time in knowledge-gathering, sharing and innovation through research and various other collaborations.

Figure 55. Delta Development Group (Park 20|20, 2010)

Delta has practical examples in their portfolio, such as feasible housing, offices and logistics business premises that point profitable business cases. The company also has a vision on quality of living and working. (Duurzaamgebouwd, 2017).

VolkerWessels

VolkerWessels (Figure 56) is a Dutch concern with around 120 companies and 15.000 employees. They are active in three market sectors: construction & real estate, infrastructure & energy & telecom. They develop, design, build, finance, manage, operate and maintain for their stakeholders: clients, financiers, employees, suppliers and society in a broad sense. It is a company that utilizes opportunities and introduces sustainable innovations.

Figure 56. VolkersWessels (Park 20|20, 2010)

Reggeborgh

Reggeborgh (Figure 57) is a private investment company based in Rijssen, which invests mainly in construction, real estate, fiberglass, financial services and energy.

Figure 57. Reggeborgh (Park 20|20, 2010)

Property investments are based in the Netherlands, Germany and Canada. Reggeborgh is involved in the entire property value chain: finance, purchase, development, construction, investment, asset management and property management.

William McDonough + Partners

Originally from the United States, William McDonough (Figure 58) is an internationally recognized author, architect and designer, who specializes in sustainable development and the circular economy. He is the founder of the architecture and planning firm William McDonough + Partners, the principal designer of Park 20|20. Together with Michael Braungart he co-founded MBDC, a C2C consulting firm, and other non-profit organization that allow further cradle to cradle thinking, such as GreenBlue and the Cradle to Cradle Products Innovation Institute.

Figure 58. William McDonough + Partners (William McDonough + Partners , 2017)

Municipality of Haarlemmermeer

The master planning process involved consultation with municipality planners (Figure 59) to ensure that Park 20|20 respected the regional and municipal master plans. Community interests were represented in the review and approval process, including policy and technical review by appropriate Aldermen and the City Council. Park 20|20 master plan received unanimous approval by the City Council of Beukenhorst in June 2009.

Figure 59. Gemeente Haarlemmermeer (Gemeente Haarlemmermeer, 2017)

(William McDonough + Partners, 2010).

Material suppliers

Finding C2C material suppliers was not easy, as there were very few suppliers that had C2C-certified materials available. After asking 72 suppliers to provide products close to being C2C materials, they found 41 suppliers that either had C2C-certified materials or were confirmed to supply adequate alternatives where no C2C materials existed (Scott, 2014). With these suppliers, several long-term relationships and contracts were developed, to allow for product leasing arrangements. This way, suppliers are encouraged to take responsibilities for their materials, and to return nutrients to their appropriate cycles. (William McDonough + Partners, 2010).

Contractors

Different organizations were involved in the success of Park 20|20.

- **Arizona State University**: Investigated the impact of the workplace on employee productivity.
- **TU Delft**: Provided solutions for the processing of biological waste in the park and the treatment of grey water.
- **Ellen MacArthur Foundation**: Information on the application of the circular economy in the urban area.
- **Dutch Green Building Council**: Certification of buildings.
- **C2C Products Innovation Institute**: Provided training courses to stimulate certification of Cradle to Cradle products.
  (Park 20|20, 2010).

4.6.4 Biological and technical cycles

The following paragraphs will outline achievements that are realised in Park 20|20 concerning the integration of circular economy in their buildings as well as other relevant achievements.

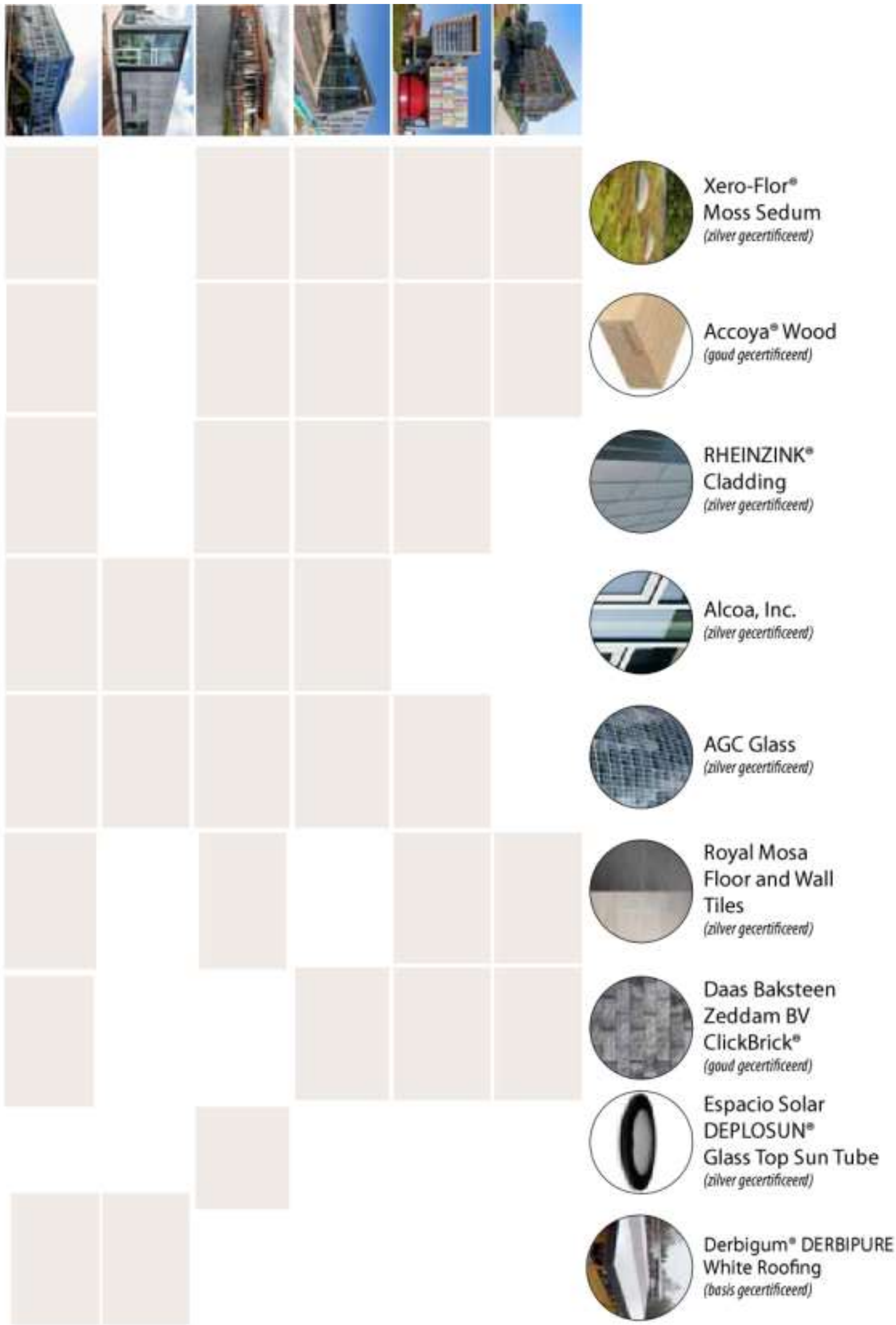
4.6.4.1 Cradle to Cradle

The materials used in Park 20|20 are as much C2C-certified as possible. For a material to be C2C-certified, it must meet strict standards regarding environmental friendliness, health for users, reusability, technical and biological cycles, and the honesty of the production process (Park 20|20, 2010). Biodegradable materials such as food, fibre and wood are used. Technical materials are reusable in another life such as metals, glass and plastics (William McDonough + Partners, 2010). The amount of certified products applied at Park 20|20 increases every year through research and innovation (Park 20|20, 2010).

An example of C2C design in buildings would be parts of the building that are seen as “technical nutrients” rather than ultimately a waste product. These technical nutrients can be reused after they have fulfilled their current purpose, which greatly increases the value of said product. For example, a steel beam in a building is still in usable conditions 15 years. (Scott, 2014).

All buildings of Park 20|20 were equipped with window panes from AGC, the only C2C glass manufacturer in Europe, which reduced the average cost (per unit) of furnishing (C2C-Centre, 2017)

Figure 60 shows the C2C materials used in the buildings of at ark 20|20.


Xero-Flor® Moss Sedum
(zilver gecertificeerd)
Accoya® Wood
(goud gecertificeerd)
RHEINZINK® Cladding
(zilver gecertificeerd)
Alcoa, Inc.
(zilver gecertificeerd)
AGC Glass
(zilver gecertificeerd)
Royal Mosa Floor and Wall Tiles
(zilver gecertificeerd)
Daas Baksteen Zeddam BV ClickBrick®
(goud gecertificeerd)
Espacio Solar DEPLOSUN® Glass Top Sun Tube
(zilver gecertificeerd)
Derbigum® DERBIPURE White Roofing
(basis gecertificeerd)

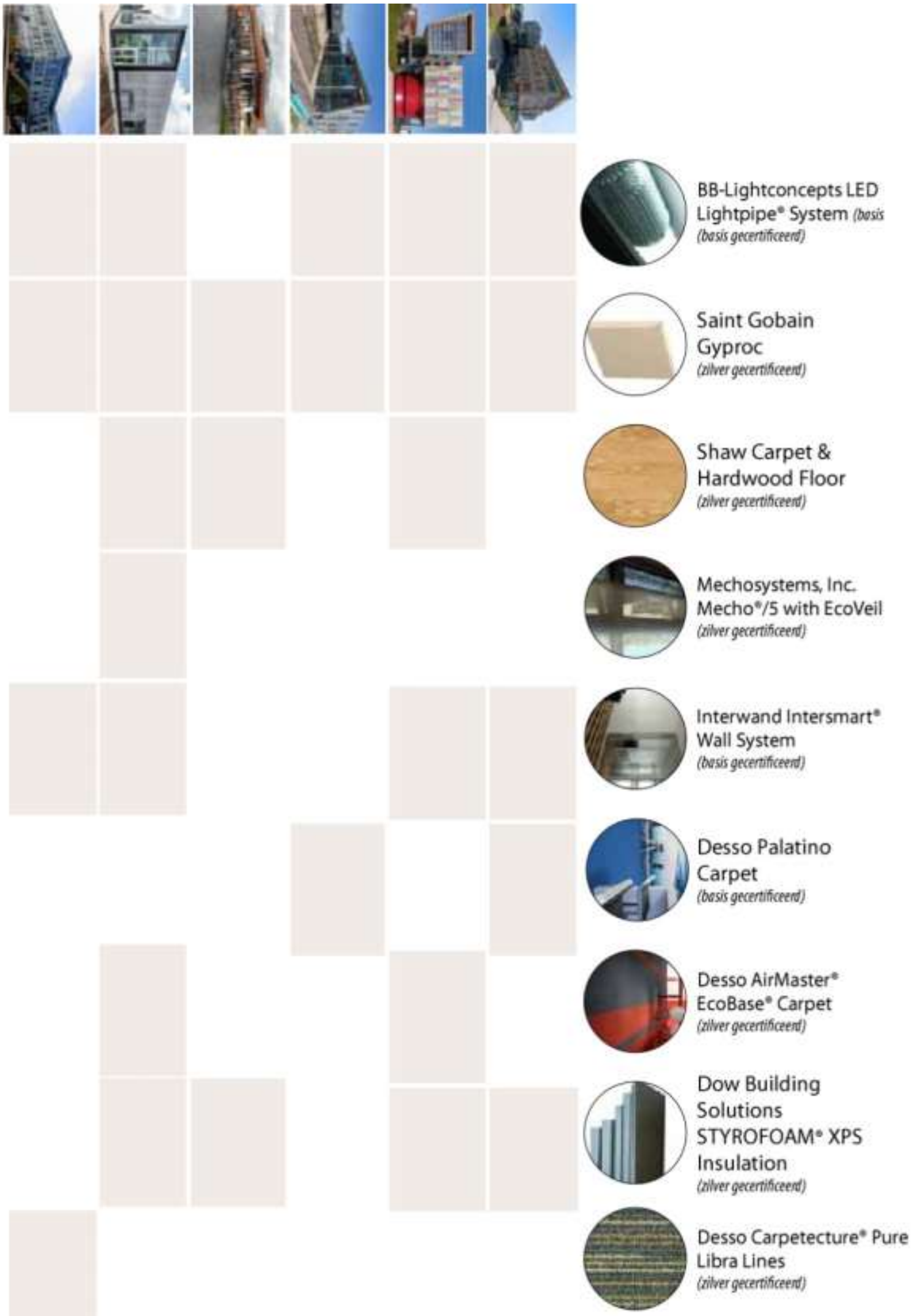


Figure 60. Buildings and C2C materials used at Park 20|20 (C2C-Centre, 2017)

4.6.4.2 Design for disassembly

As stated before, disassembly is an important part of the circular economy and therefore of Park 20|20. The buildings are designed to be easily disassembled or reconfigured, which allows for innovation. For example, if an innovative technology to save more heat energy would be developed that involved changing windows, these could easily be replaced in the buildings at Park 20|20. This applies to nearly all parts of the buildings, which allow the buildings to keep their value over time and preventing them from becoming outdated. In this way Park 20|20 adequately considers future technological innovations in its current design. (Scott, 2014) Detailed plans are kept describing the exact materials used and where they were placed. The design also included reducing the weight of buildings, to allow for easier replacement and effective reuse of products in other production processes or as new raw material (C2C-Centre, 2017).

4.6.4.3 Solar energy

In Park 20|20, solar energy is used as part of the solution to become fully sustainably powered. Green roofs equipped with PV (PhotoVoltaic) (Figure 61) arrays provide the community with a renewable carbon-free energy source. The plants used on the roofs reduce surface temperatures.

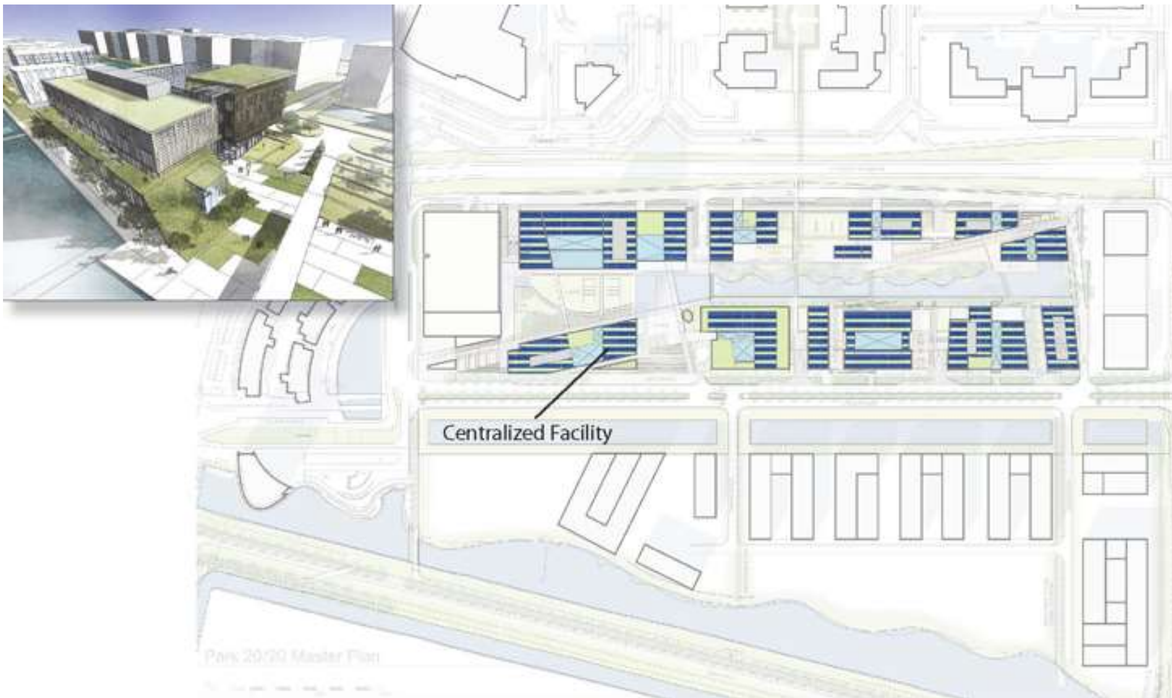


Figure 61. Map of photovoltaic arrays surface in Park 20|20 (Asla, 2010)

For optimal building placement, a solar path diagram was made (Figure 62), which maps the path of the sun through the day and year to determine optimal solar orientation. This enabled the developers to angle buildings in a direction that maximized sun exposure during winter and shade during summer (Asla, 2010). To ensure optimal daylight use for the green roofs and the buildings' interiors, size and mass of the buildings were adjusted accordingly. Also, by installing monitoring systems transparency of energy consumption patterns was created, which allows for the possibility of further energy saving (William McDonough + Partners, 2010).

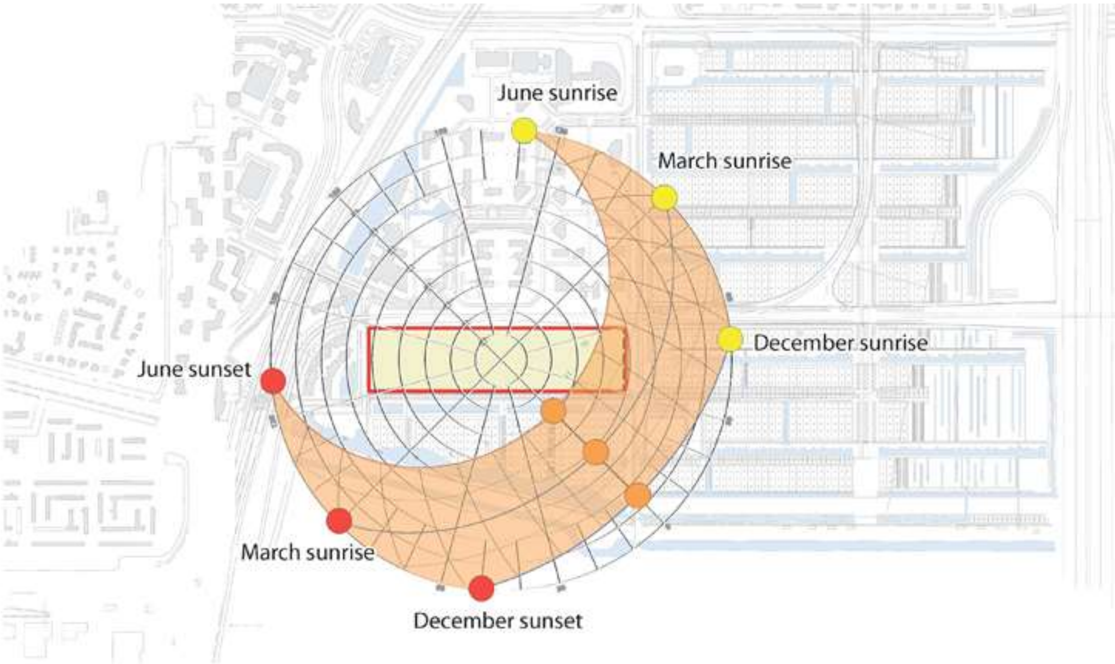


Figure 62. Solar path diagram (Asla, 2010)

4.6.4.4 Hot and cold storage

To regulate the temperature Park 20|20 uses geothermal heat pumps. During the summer, cold water stored underground is used to cool the building through a loop of pipes, which is piped back into the storage once it has become too warm. During the winter the process is reversed, as warm water is used to heat the building, returning cold to the basin. (Singhal, 2014).

4.6.4.5 Water purification

At its core, Park 20|20 uses a ‘closed loop’ water-management system to treat and reuse wastewater (Figure 63). To accomplish this, a building’s wastewater is directed to a central treatment facility where it is purified with helophyte filters and then re-circulated to buildings for use in toilet flushing. Heat generated in the process is used to create hot water for the area’s hotel. The solar-powered water treatment facility reduces waste and water usage by 90 %. (C2C-Centre, 2017).

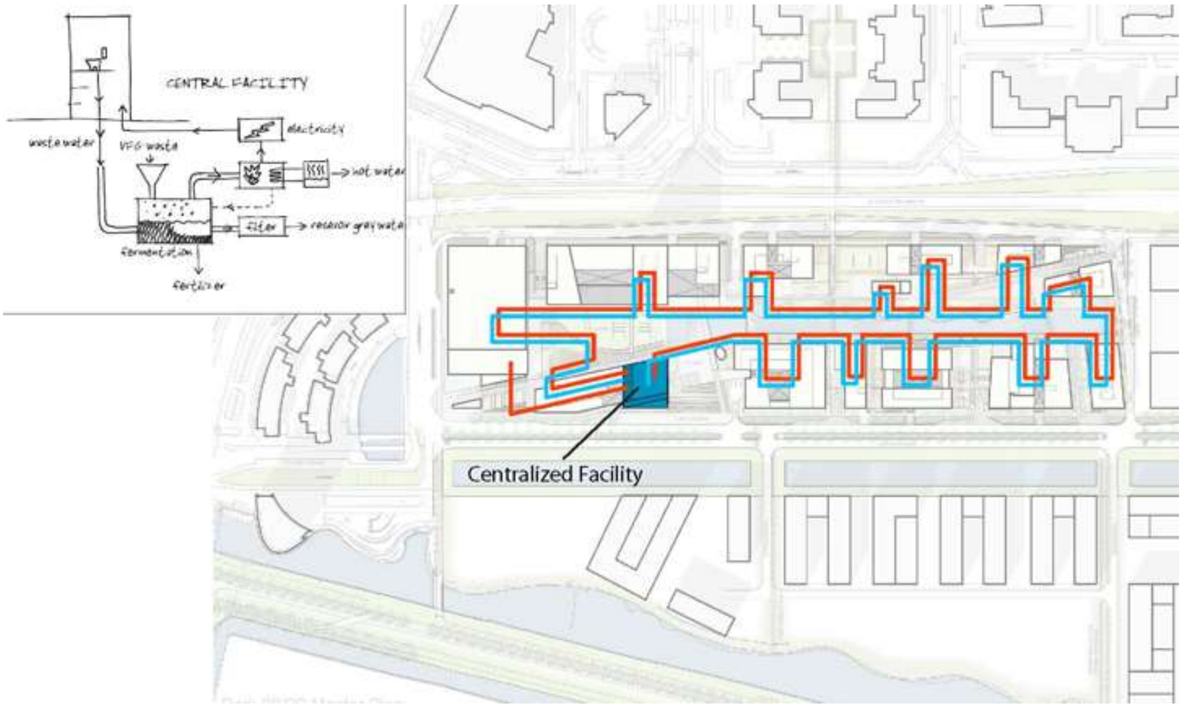


Figure 63. Waste water, heat and power system (Asla, 2010)

Green roofs absorb rainfall and increase biodiversity. Runoff and overflow are directed to on-site storage (Figure 64).

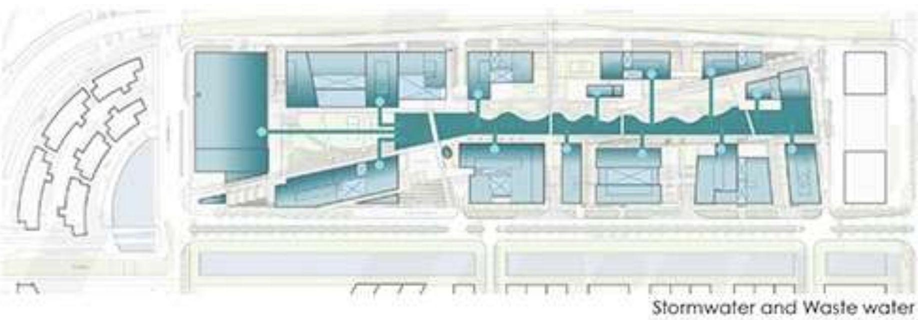


Figure 64. Storm water and wastewater (Asla, 2010)

The wastewater treatment is part of Park 20|20 agenda of waste-free design, which is in line with the C2C principles. This agenda also includes the capturing of energy and soil amendments, and eliminating sewage discharge.

(William McDonough + Partners, 2010) (Asla, 2010)

4.6.4.6 Wind orientation

Wind is used as a passive energy reduction strategy. A wind rose diagram was made to determine the wind speeds on-site for building ventilation strategies (Figure 65), and to determine the speed and direction of winds in winter for optimal protection strategies. This reduces energy demand and provides fresh air for human well-being. (Asla, 2010).

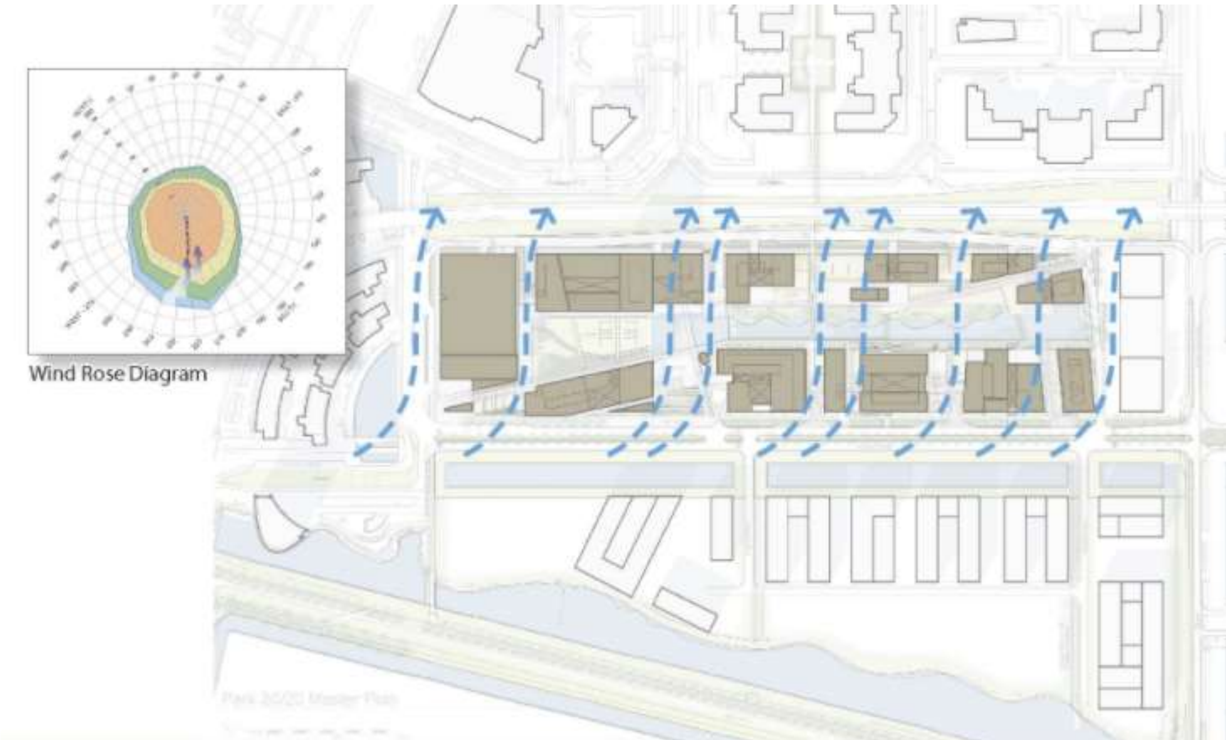


Figure 65. Wind and Ventilation (Asla, 2010)

4.6.4.7 Regeneration of the environment

To increase biodiversity and create a healthy ecological environment, Park 20|20 has constructed an environmental plan that aims to establish clean and healthy water flows, improve air quality, increase photosynthetic productivity, build healthy soils in greater quantities than before development, and increase connectivity between ecological landscapes (Figure 66).

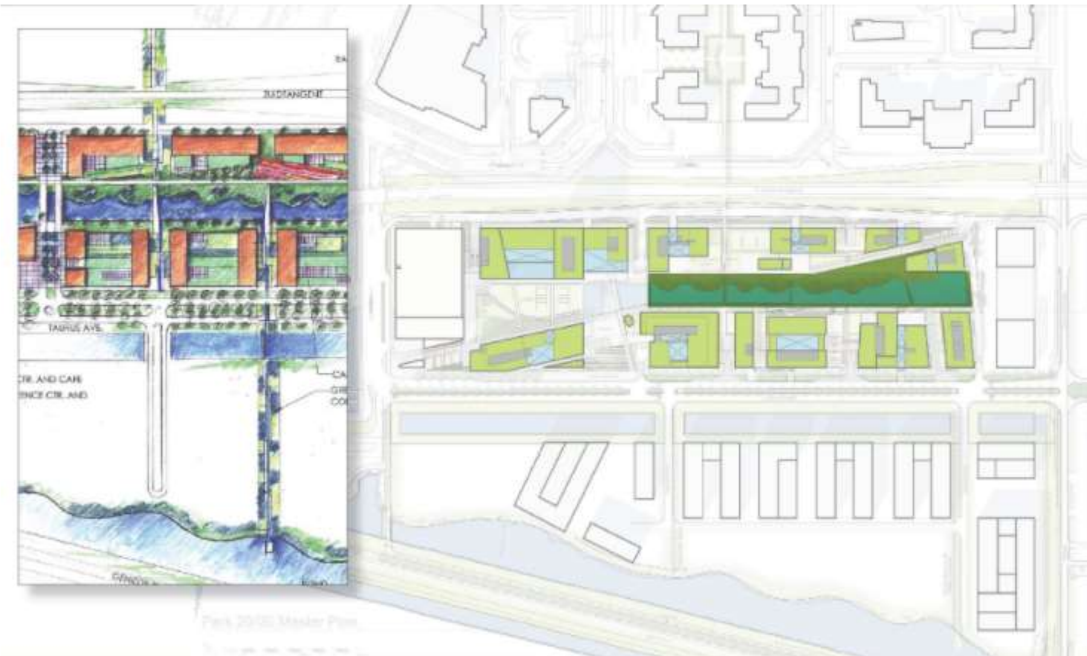


Figure 66. Ecology and biodiversity (Asla, 2010)

The landscape plan combines the municipality’s design of rational, quadrated streetscape planning with informal and diverse greenery in the internal canal garden, but also ensures the planning of Park 20|20 is respectful of regional ‘cultural landscape’ and the template of the ‘polder grammatical’. The plan’s introduction of diverse plant palettes creates biologically robust gardens, and connects these interior gardens with the regional natural environment through landscape corridors. It also creates additional green areas on roofs and parking decks. Altogether, the addition of these green environments increases photosynthesis, insulate buildings, stores carbon dioxide, produces oxygen, builds soil and biomass, and filters air and water. Furthermore, flowering plants have a positive effect on human well-being, and the on-site wetlands and gardens allow birds to nest, rest and feed. (Asla, 2010) Part of the green vegetation is a butterfly garden, a bee garden and a vegetable garden for urban farming (Figure 67).

Figure 67. Urban garden Park 20|20 (Park 20|20, 2017)

As the Netherlands have a unique canal system that includes flooding and water level stabilization, it had to be made sure that the landscape plan of Park 20|20 did not drastically alter the regional aquatic environment, which is why polder water management was studied. (William McDonough + Partners, 2010).

4.6.4.8 Human well-being

The architecture of Park 20|20 is people-oriented and aims to support its occupants' well-being by creating elegant, well-lit interiors that ensure a good connection between employees and available daylight. The buildings of glass and steel with integrated greenery, modern installation techniques and high-quality finishes also supports creativity and inspiration and is aimed to be user-friendly. Apart from this fresh, clean air should be available to everyone, to increase comfort, productivity and health. On top of this, inhabitants are protected from harmful exterior elements such as noise, pollution, mould and infestations of any kind. Thanks to the present interior gardens, the environment encourages relationships between nature and man-made communities. The materials used present no negative effects on either the environment or humans, and are therefore safe to use indefinitely. All this is part of Park 20|20's belief that a good business park can be beneficial to human well-being in many ways, while still promoting environmental health and sustainability.

(Park 20|20, 2010) (William McDonough + Partners, 2010).

4.6.5 Economic viability

Delta is engaged in the development of models for valuation and construction to make C2C buildings economically attractive. Some of the aspects that contribute to financial success are:

- **Quality of the buildings**: helps the buildings to be sold quickly to at a higher price (from € 135 per m^2 for € 210 per m^2). The Bosch Siemens Home Appliance Group office and product showroom was sold in 2011 with a 23 % return.
- **Increase in productivity**: around 5 % is measured after a one-year internal review of the Bosch Siemens building showing. This results in a major saving for tenants.
- **Financial lease**: of materials for buildings in which the material suppliers remain owners. The results in lower upfront cost due to payment for use instead of ownership.
- **Involvement of building engineers**: early in the design process reduced the construction cost by about 20 %.
- **Reduced average cost for grey water recycling**: by sharing the cost of grey water purification over several units.
- **Site-wide heating & cooling**: results in lower cost of mechanical installations for each building.
- **Site-wide capacity to use e.g. solar panels**: reduces initial cost for the hardware.

Costly testing and conducting an efficient supply chain was a barrier in realising profitable C2C buildings. However, this only needs to be done once.

(Scott, 2014) (C2C-Centre, 2017)

4.6.6 Influencing factors

The following chapter describes several influencing factors in the execution of park 20|20.

4.6.6.1 Legislations

Legislation in general hindered the execution of the project, due to resentment of municipalities to change legislations (Van Der Meer, 2015) and leasing agreements of building materials which impede with project ownership legislation (Scott, 2014).

4.6.6.2 Know-how

Regarding the know-how of the involved parties, a couple of influencing factors can be stated:

- The good understanding of the economic, social and environmental advantages of C2C encourages the stakeholders.
- The concept of C2C is perceived as abstract which hindered the understanding of it.
- The project schedule was extended due to the need for target reconstruction, costs caused by the financial crisis, and the time-consuming search for right material suppliers and C2C material innovation processes.
- Stakeholders of C2C building do not yet always have the same expert knowledge as non C2C stakeholders.
- Information on required stakeholders for C2C buildings was not always available.
- Effective communication between stakeholders of C2C buildings stimulates the implementation.
- Training for suppliers and users were organized at Park 20|20, which stimulates cooperation and network processes towards C2C building.

(Van Der Meer, 2015)

4.6.6.3 Stakeholders and supply chain

According to the thesis of Van Der Meer, the following factors were determined about the supply chain and among stakeholders that influenced the project:

- Beforehand it was not clear whether the project would be successful. This lack of thrust in the project hindered its development.
- The municipality did not approve the infrastructure planning of Park 20|20 in the beginning.
- Stakeholders did not feel comfortable to work with new partners in the beginning.
- The cooperation of national architects with a foreign specialist in C2C design stimulated the project.
- The collaboration of different parties such as engineers, developers, contractors, municipality, users, suppliers and architects had a positive influence on the project.
- The integration of the building sector in the design process resulted in a turbulent process in the beginning.
- Learning and innovation has been an important aspect in the process where C2C materials where not always available.
- The buildings sector is not always motivated to rethink their way of working.

(Van Der Meer, 2015).

4.6.7 Rating and conclusion

Park 20|20 has high ambitions on circularity through its C2C design approach. Using sustainable materials, advances installation techniques, air purification, ergonomic and appealing design, daylight and green elements, a healthy and inspiring work environment is created. The buildings protect the users from elements such as noise, mould and infestations.

According to the ReSOLVE framework, Park 20|20 covers the following aspects of CE:

Regenerate	Green roof, water flows, nature sides with species diversity and optimized linkage of site landscape are used to increase and regenerate regional ecosystems. The embedded nature sequesters carbon, makes oxygen, builds soil and absorbs, filters air and water.
Share	The buildings are designed for disassemble to allow for reconfiguration and reuse the materials, increasing the residue value.
Optimise	Water waste is reduced by 90 % through the use of a "closed loop" water-management system.
Loop	For the construction of the buildings C2C materials were used. However not all materials meet the standard since the supply of Cradle to Cradle materials is not yet sufficient.
Exchange	Renewable energy and energy efficiency is achieved through the use of photovoltaic arrays, heat and cold storage, as well as wind orientation for ventilation.

Influencing factors such as changes needed in regulations and laws required for C2C building were hindering the adoption of CE. Regarding the know-how of the parties involved it can be concluded that the concept of C2C was perceived as abstract, which hindered the understanding. There has also been a lack of knowledge, both in expertise and the knowledge about the required stakeholders. However, good training stimulated cooperation and network processes towards C2C building. The fact that stakeholders felt uncomfortable working with new partnerships combined with the building sector being traditional and conservative, discouraged companies to rethink their practices in terms of C2C. Park 20|20 covers buildings with different levels of BREEAM certificates, from very good to excellent as can be seen in Figure 54.

4.7 Bionorica Headquarter

Bionorica AG (Aktiengesellschaft, in English: stock corporation) is a German company situated in southern Bavaria. It was founded 85 years ago (in 1933) and by now it has developed to “one of the leading global manufacturers of herbal medicines” (Bionorica SE, 2017). The new headquarter in Neumarkt, Germany was built in 2007 combining innovative energy technologies and intelligent materials. The company itself states about the building: “The new company headquarters is one of the most sustainable office buildings in Europe and thus an expression of the company philosophy being put into practice. […] [It] represents a milestone in construction with reference to ecological effectiveness, environmental friendliness and health compatibility for the employees” (Bionorica SE, 2017).

Figure 68. Bionorica SE (Bionorica SE, 2017)

4.7.1 General information

Figure 69. Bionorica Headquarter (Bionorica SE, 2017)

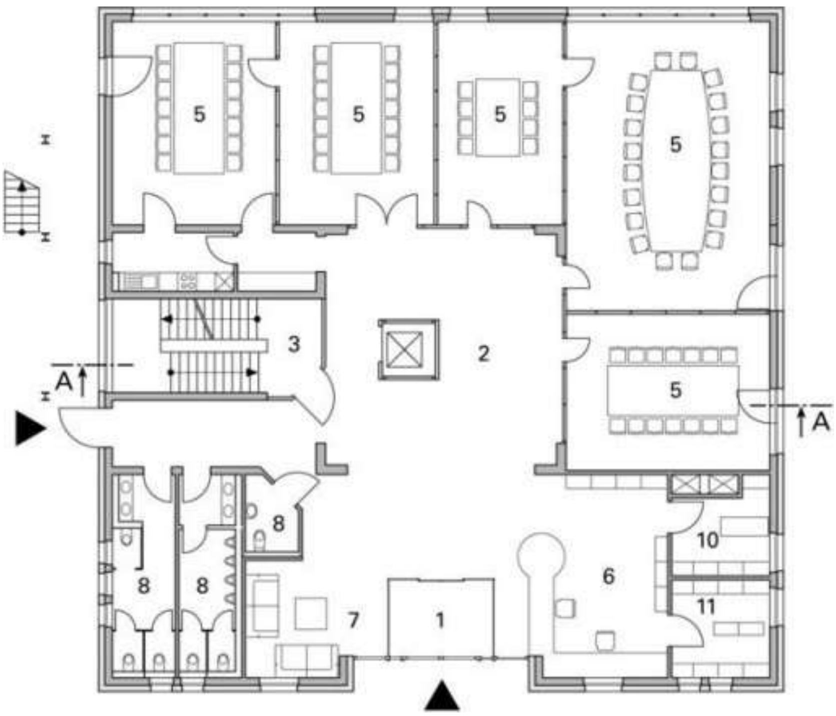


Figure 70. Bionorica Headquarter - Ground plan of first floor (bba, 2008)

Name: Bionorica Headquarter

Location: Neumarkt, Germany

Construction year: 2007

Architect: Wolfgang Brummer (company: Brummer und Retzer, located in Amberg, Germany)

Manufacturing company: See chapter 'Biological and technical cycles'

Type of building: Office Building

Area: Approximately 480 m^2

Tags: Regenerate, Optimise, Loop, Virtualise, Exchange

Link: http://www.c2c-centre.com/project/bionorica

4.7.2 Project goals

Located in Germany, Bionorica AG is a leading global manufacturer of herbal medicines. They therefore have energy demanding manufacturing processes and extensive clinical and pharmaceutical studies. Energy saving, and energy production was one focus, but the overall aim was a building that contributes to the environment. It had to be in harmony with nature as sustainability is a main part of the company's philosophy. The new headquarter had to express this in practice.

The aim was not to build another low energy house or a building that focuses only on one aspect of sustainability. “The construction and the materials used for this purpose were to cause as little burden on the environment as possible” (C2C centre, 2017).

To reach this goal special toxic free concrete, air filtering colours, recyclable textiles and dismantable furniture were used. (For more information about the technical solutions, see chapter ‘Biological and technical cycles’)

4.7.3 Supply chain

The building is meant to be completely recyclable. Therefore, special materials and products were used to build the headquarter. Outstanding are the carpets and windows which are only leased and will be returned to the supplier after a specific time (see Figure 71).

The furniture is designed for disassembly and recyclable to high percentage. Even the textiles used are meant to go back in a loop and be part of a new product again. For all non-recyclable materials Bionorica has a take-back guarantee. (Braungart, 2012)

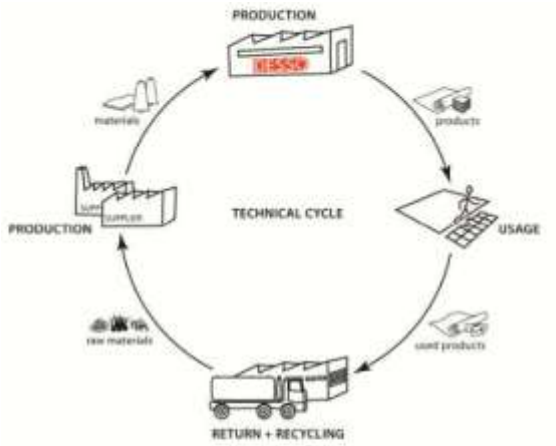


Figure 71. Example: supply chain carpets (Braungart, 2014)

4.7.3.1 Summary of companies involved

Figure 72 shows some companies that were involved in the project and supplied cradle to cradle or environment friendly products. A more detailed list of companies and their contribution to the building is given in Table 6.

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Figure 72. Manufacturing companies involved (Braungart, 2014)

Table 3. List of companies involved

Company	Contribution	Company logo
Art aqua	Water walls and green walls	**Figure 73. Art aqua (Art Aqua, 2017)**
Backhausen	Recyclable interior textiles	**Figure 74. Backhausen (Backhausen, 2017)**
Desso	Dust control flooring	**Figure 75. Desso (DESSO, 2017)**
Elektro Lück	Lighting design	**Figure 76. Elektro Lück (Elektro Lück, 2017)**
EPEA	Ecological material evaluation	**Figure 77. EPEA (EPEA, 2017)**

Farmbauer	Heating, sanitation and ventilation	**Figure 78. Farmbauer (Farmbauer, 2017)**
Grammer Solar	Contributions to solar roof	**Figure 79. Grammer Solar (Grammer Solar, 2017)**
Heidelberg Cement	Defined concrete additives	**Figure 80. Heidelberg Cement (Steelguru, 2017)**
Herman Miller	Air and skin-safe furniture	**Figure 81. Herman Miller (Herman Miller, 2017)**
Korsche Metallbau GmbH + Co. KG	Façade construction	**Figure 82. Korsche Metallbau (Korsche Metallbau, 2017)**
MSCN - Martin Stanscheit Corporate Navigation	CI (corporate identity) consultancy	**Figure 83. MSCN (MSCN, 2017)**

Schüco	Photovoltaic windows and skylights	**Figure 84. Schüco (Schüco International KG, 2017)**
Xeroflor	Interior and exterior vegetation	**Figure 85. Xero flor (Xero flor, 2017)**
ZAE Bavaria	Thermal building simulation	**Figure 86. ZAE Bavaria (ZAE Bayern, 2017)**

4.7.3.2 Construction planning

The Bionorica Headquarter was planned by a cooperation of several companies. "A thermal building simulation was carried out by the Centre for Applied Energy Research in Bavaria (ZAE), and plant engineering was also tested" (ZAE Bayern, 2017). Also, special about the project is "that the entire energy technology was not divided up into the individual specialist planners. Ventilation, heating, refrigeration, electrical and solar technology were grouped under a single bracket and then divided into individual departments" (bba, 2008).

4.7.4 Biological and technical cycles

Figure 87 shows some examples of special cradle to cradle principles realized in the Bionorica Headquarter. In the following chapter the biological and technical cycles of products and materials used for the building are explained. The chapter is divided into several subchapters according to the areas (e.g. 'construction base', 'inside', 'outside') of the building.

Figure 87. Added value (C2C BIZZ, 2014)

4.7.4.1 Construction base

The Bionorica headquarter is built of materials whose production and use do not pollute nature. The building is PVC (Polyvinyl chloride) free. The steel does not contain any rare non-ferrous metals. The processed concrete of Heidelberg Cement is free of nitrogen oxides and organic hydrocarbons. The concrete additives do not contain heavy metals and halogen compounds. The cement was made without using substitute fuels to ensure low natural radioactivity (bba, 2008). The nitrogen pollution in the air is even reduced by the so called ‘TioCem’: nitric oxide from the ambient air is converted into nitrate (NO_3^-) which is washed as a nutrient in the soil when it rains (see Figure 94). (Braungart, 2014)

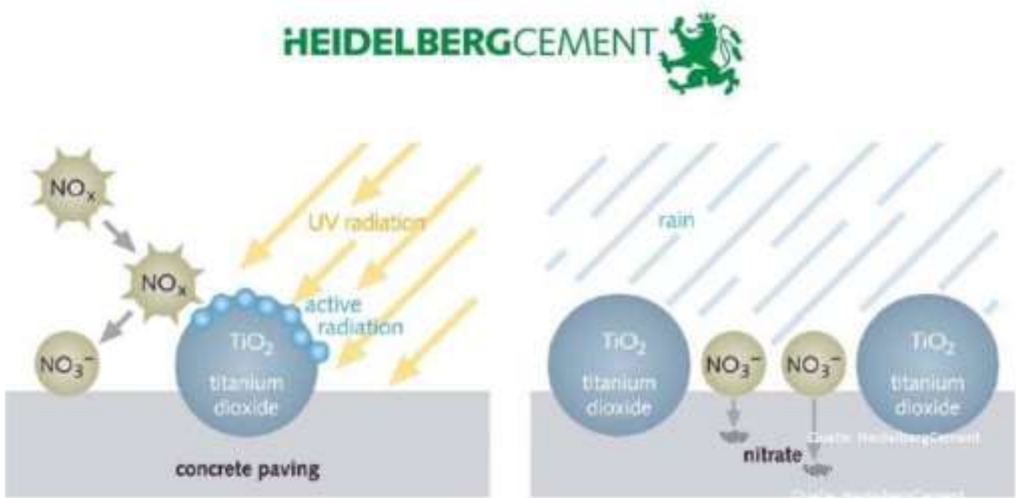

Figure 88. Heidelberg Cement - 'TioCem' (Braungart, 2014)

4.7.4.2 Outdoor

Solar modules

The building has a carbon-neutral energy supply and produces more energy than it consumes throughout the year. The surplus is fed into the social electricity grid. (Tay, 2010) This is achieved with solar energy: The four-storey building has a slightly inclined, flat roof of approximately 480 m² built of Photovoltaic (PV) modules. These individual formable PV modules can be used in all areas of the building envelope. The ProSol PV modules are also used on the southeast façade (see Figure 89) generating electricity both from the inside and the outside. (bba, 2008)

Figure 89. Solar modules (Schüco, 2017)

Windows

The windows are delivered by the German company Schüco. They are triple glazed (see Figure 90) with concealed fitting providing high thermal insulation properties. (Fensterplatz, 2007) Special about these widows is that they are leased for 25 years and will be returned to Schüco to make new windows. (Tay, 2010)

The remaining facade was insulated on the outside with 20 cm mineral foam boards providing high energy savings. (bba, 2008)

Figure 90. Schüco window (Schüco International KG, 2017)

Green façade

Bionorica Headquarter has a green façade made by Xeroflor, a German green roof supplier. There are several advantages the green facades provide to the building: First the plants enrich the air with oxygen and reduce CO_2 content as well as dusts and gases from the air. Green facades also store water and therefore relieve the public sewage system. Additionally, they reduce noise by reflection and partial absorption and provide thermal insulation as well as protection of the facades skin from external damage. The overall concept and system of layers in shown in Figure 91. (Xero flor, 2017)

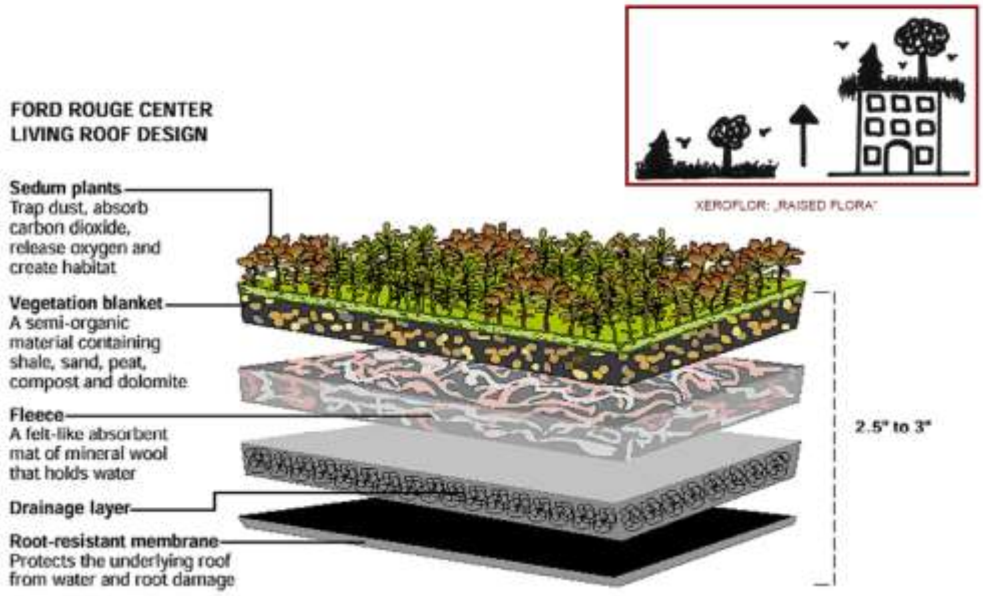

Figure 91. Xeroflor 'Raised flora' (Braungart, 2014)

4.7.4.3 Indoor

Leased carpets

The German Cradle to Cradle certified company Desso delivered dust control flooring (carpets) to the Bionorica Headquarter. Special about these carpets is first that they are only leased meaning that Desso takes back the used carpets and recycles them again. The healthy closed loop system based on Cradle to Cradle principles which Desso calls 'ClosedLoopCarpet' is also unique. The company hereby focuses on the most effective methods to separate materials. The yarn and other fibres from the backing are separated, producing

> "two main material streams which can be recycled. After an additional purification stage, the yarn (with the required purity) is returned to the yarn manufacturer for the production of new yarn. In the entire process, some virgin material is needed to compensate for losses and process inefficiency. Today's bitumen backing is recycled as a valuable raw material for the road and roofing industry. All non-recyclable fractions will be used as secondary fuel in the cement industry." (Desso, 2017)

Special about Desso carpets is also the quality. The urban indoor air quality is in general three to eight times worse compared to outdoor air due to off-gassing of chemicals from indoor fittings. Desso carpets, in contrast, have "fibres that actually improve air quality, instead of off-gassing VOCs (volatile organic compounds) and other toxic compounds" (Tay, 2010).

To make sure the carpets are of the best possible quality, every supplier needs to undergo a 'Material Health Assessment of products and material ingredients'. For this, a product declaration needs to be filled in by the supplier being the basis for a third-party material health-assessment by EPEA (Environmental Protection Encouragement Agency, a scientific research and consulting institute). If the product assessment is graded positive the material can be purchased. (Desso, 2017)

Water walls and green walls

The company Art Aqua delivered indoor water walls and green walls to the Bionorica Headquarter. They regulate the humidity level in rooms, eliminate pollutants in the air and thus help to create a health and performance-enhancing indoor climate. (Art Aqua, 2017)

Figure 92 shows an example of a green and water object installation in a business office.

Figure 92. Indoor green and water object installation (Art Aqua, 2017)

Recyclable furniture

The office furniture meets the requirements of C2C (cradle to cradle). For example, the MIRRA chair of the German office furniture supplier Herman Miller is used. The materials used have largely a green chemistry composition and most of the parts are recyclable. The chair is overall PVC free and designed for rapid disassembly (see Figure 93). (Rossi, et al., 2006)

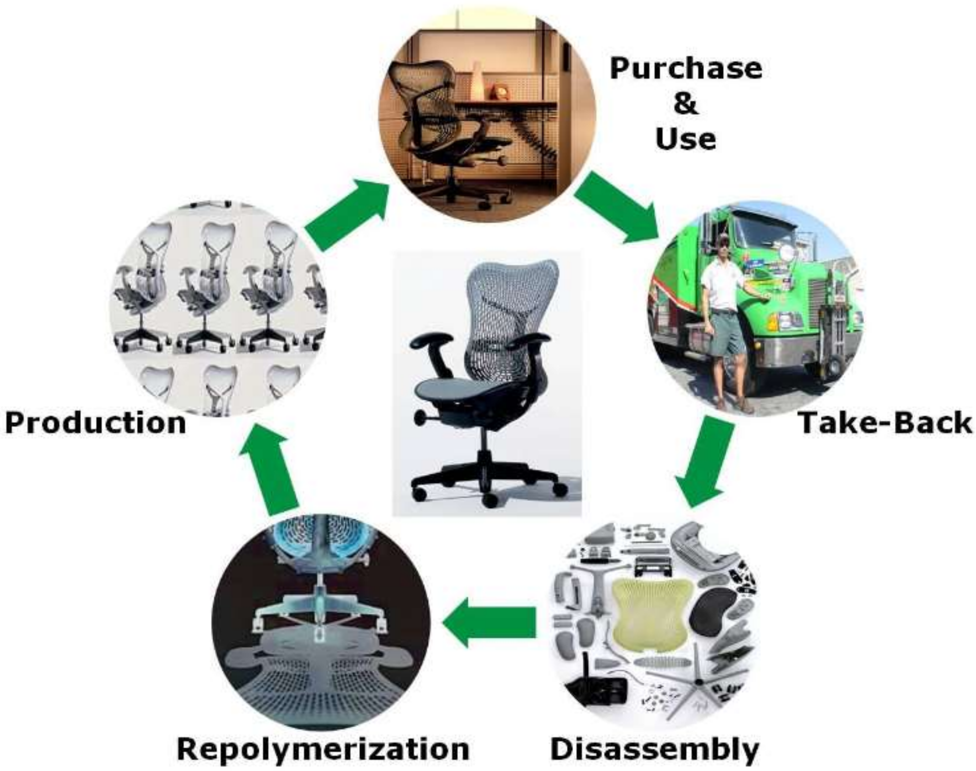

Figure 93. C2C MIRRA chair by Herman Miller (Braungart, 2012)

Recyclable textiles

The Austrian company Backhausen provides furniture and decorative fabrics based on C2C principles. The company offers a return guarantee for all their products. The textile line called ‘Returnity’ is environmentally friendly produced using 100 % recyclable fabric (see Figure 94). At the end of the products’ lifecycle, the fabric is taken back to be useful in infinite ways in new products. (Perkins, 2012)

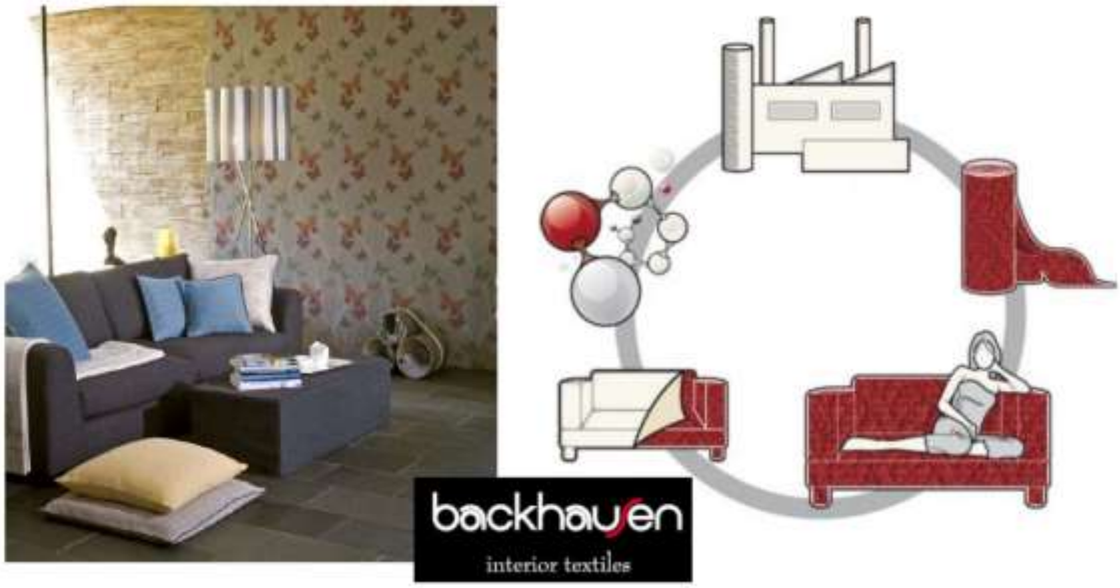

Figure 94. Backhausen 'Returnity' (Braungart, 2014)

4.7.4.4 Others

Colour

The protection coating is harmless to the groundwater. (Handelsblatt, 2017) The room colours do not cause harmful odour and actively clean the air. (Greenbuilding, 2009)

Ventilation

“The building makes use of plant-based air filters and high performing insulating materials that also improve the air inside the building.” (Tay, 2010)

4.7.5 Influencing factors

The following chapter describes several influencing factors in the execution of Bionorica Headquarter.

4.7.5.1 Law and incentives

Germany has annual construction and demolition waste (including road construction) of 209,5 million tonnes (2014). That means over half of the overall annual waste produced in Germany (401 million tonnes in 2014) is caused by the construction industry. Still Germany has a recycling rate of roughly 90 % of mineral building waste. (ALBA Group, 2017)

The recycling law in Germany which was implemented in 1994 defines the waste disposal according to the polluter pays principle. It is based on the principle that waste is to be avoided first and secondly materially or energetically used. Meaning only if the non-usability is proven an environmentally friendly disposal can take place. (Mettke, 1995) Usually the implementation is predominantly via the commission of private waste disposal companies. 40 % of construction and demolition waste is used to fill former mining facilities. Just under 10 % is processed into the recycle of building materials for the use in deep building measures. (BDE, 2016)

In 2017 a new law called 'Mantelverordnung' came into effect. It regulates the production of mineral replacement building materials from construction and demolition waste. Furthermore, it states which materials may be used to fill excavations or opencast mines and for which materials other recover or disposal opportunities must be found. (BMUB, 2017)

4.7.5.2 Geographical influences

The Bionorica Headquarter is located in southern Germany. In general, the country has relatively large deposits of brown coal, potash and rock salt as well as stones and earths for the building industry. These resources are mainly situated in northern Germany. (Geotechnologien, 2017) Having currently enough resources available might be a reason for the poor percentage of circular economy buildings in Germany. Nevertheless, the country has attempts of being environmental friendly, as the high recycling quote of mineral building waste by roughly 90 %, mentioned in the previous chapter. Apart from recycling, Germany also focuses on solar energy. In 2014 half of the needed energy was produced by solar panels. (WirtschaftsWoche, 2014)

Energy production and energy saving are therefore a main aspect in the building industry nowadays in Germany. In 2015 there have been built over 100.000 new low energy houses. Compared to 2010 the figure doubled. (Hermelink, 2016)

To minimize the power consumption special energy saving windows, walls and thermal insulation are used. To produce energy, solar panels on houses are a current trend in Germany. Apart from that there are also some construction trends concerning the interior design. First the flexibility of rooms is a main issue of clients meaning that rooms are kept open with less weight-bearing walls to make adaptions in the future. Secondly there is real wood flooring used instead of laminate floor which might contain harmful substances. This trend of avoiding harmful materials also applies to the wall paint as natural lime plaster instead of wallpaper is used. In general, the choice of materials is made with focus on durability, health promotion and sustainability. (Bauhaus Portal, 2017)

4.7.5.3 Know-how

The Bionorica Headquarter was designed by Wolfgang Brummer from the company Brummer and Retzer in Amberg, Germany. He had no special knowledge about cradle to cradle but learned about the topic very fast. (Greenbuilding, 2009)

The project was accompanied by several C2C-specialists, e.g. the EPEA (Environmental Protection Encouragement Agency, a scientific research and consulting institute) which also made the analyses of the used materials. (EPEA, 2017)

4.7.6 Rating and Conclusion

According to the ReSOLVE framework by the Ellen MacArthur Foundation, the building covers the following aspects of circular economy:

Regenerate	The Bionorica Headquarter produces its own renewable energy partly via PV modules on the roof and façade. The materials used are to be recyclable and for those materials that are non-recyclable a take-back guarantee from the supplier is offered.

Share	The lifetime of certain products, e. g. office furniture, is prolonged as they are built modular and parts can be exchanged easily.
Optimise	Several products used in the building have been optimised by other parties, e. g. the office chair MIRRA that is meant to be disassembled or the green façade that makes the outer wall useful in terms of insulation.
Loop	Most of the products implemented in the building are meant to be recycled and used again, e. g. carpets, furniture and textiles that are returned to the supplier who makes new products out of them.
Virtualise	A thermal building simulation was carried out and plant engineering was also tested.
Exchange	New services as the leasing model for windows or carpets are implemented.

The Bionorica Headquarter considers and implements several circular economy aspects. The whole building was to be as harmless to nature as possible. It is meant to be recyclable and the materials that cannot be recycled are taken back by the supplier. The building is PVC free, the cement is free of nitrogen oxides and organic hydrocarbons as well as the steel used does not contain any rare non-ferrous metals. The roof and part of the façade is made of PV modules producing energy for the building. For better thermal insulation, green façades have been installed which additionally enrich the air with oxygen and reduce CO_2 content as well as dusts and gases from the air. The windows as well as the carpets are leased and returned to the supplier at the end of their lifetime for being recycled and used in new products again. Office furniture, e. g. the MIRRA chair meet the requirements of a C2C products with focus on dismantling. The same applies to the textiles which are environmentally friendly produced and 100 % recyclable fabric. Indoor water walls and green walls regulate the humidity in rooms, eliminate pollutants in the air and thus help to create a health and performance-enhancing indoor climate.

For the project, many different companies needed to work together, release information about materials and optimize their products and manufacturing processes. Even if the building is one amongst a very small number of CE buildings in Germany, the Bionorica Headquarter is a milestone in cradle to cradle inspired buildings.

5 Conclusion

To conclude this research project made for the EPS at Novia UAS, here follows a summary of the deep research topics, the business idea and thoughts on future research in CE within the field of construction industry. The topics were divided into three different subchapters to make the chapter easier to read.

We reckon this research will give the R&D department at Novia UAS tools and knowledge to further implement CE in the Ostrobothnia region. With a list of examples containing companies, projects and buildings that match on several circular aspects, as well as deeper research on six of them, we delivered to our project customer a base for their upcoming research, that can used to find matches with similar examples in the Ostrobothnia region. This we believe will help incentivize the conversion from the current linear system to a circular one.

5.1 Best practice cases

The topics for the best practice cases were chosen from over 120 buildings that matched search terms based on the ReSOLVE framework by the Ellen McArthur Foundation. It is sometimes hard to find information about buildings, especially in English, where thoughts of CE laid specifically behind the project. Especially in Eastern European countries we concluded that there is a lack of advanced circular incentives in the building industry, as the examples were few and hard to find compared to eastern and northern Europe.

In the future, we will probably see a further growth in companies using wood as their primary building material, as it is a renewable and durable material. The conclusion can be drawn from the case of Pluspuu Talot, Finch Buildings, Villa Asserbo and several others listed on our website, that more companies will start implementing different ideas in the usage of wood as a first step into circular economy, as we likely will see companies that specifically handle recycling, upcycling and refurbishment of wooden products back to the market.

Cases as the one of the Bionorica Headquarter are futuristic and interesting. The technologies of these so called ‘plus buildings’, which produce more energy than they actually consume, as well as leasing parts of the materials used, might become part of the ‘everyday life’ in a near future. This means design to recycle the building materials as in the case of Bionorica Headquarter, Villa Asserbo and Park 20|20**.**

3D-printing is taking a leap forward in the development, as seen in Villa Asserbo and from companies listed on our website, more and more are taking up the challenge of trying to make the first widespread mass-produced 3D-printed house. The choice of material is quite broad, using options between concrete, wood and various synthetic materials. Even so, the technology has yet to be refined.

Based on the examples, we believe that flexibility, upgradability and durability will be a central thought during the designing phase of future buildings. These might be implemented not only on more outspoken buildings like De Fire Styrelser, Park 20|20 and Bionorica Headquarter, but also on small-scale projects like the ones offered by Finch Buildings or, maybe in the future more outspokenly, by Pluspuu Talot.

As a central thought in CE is the reusability, beside the implementation of the before mentioned thoughts, the implementation of reusability in the design will be applied more in future buildings. This can already be seen in the planning of Villa Asserbo, Finch Buildings, Bionorica Headquarter and Park 20|20**.**

From a legislation point of view, one can notice that laws written for the linear system can stand in the way of CE initiatives, as in the case of Park 20|20. The CE ‘know-how’ among the stakeholders in the supply chain is not always existing, which can interfere with the implementation of CE. Also, the motivation to rethink the way of working by the stakeholders is not always a fact, since it requires effort and money to be performed. The circular buildings available today, provided by pioneers in the field, together with the scarcity of materials and the ongoing growth of the world population, will help and stimulate both companies and governments in their operations towards the implementation of CE.

Finch Buildings

Finch Buildings produces modular buildings assembled from separate modules, mainly made out of FSC-certified wood. 90 % of all materials used in the modules are suitable for reuse. The company behind the buildings aims for a high flexibility through an adjustable living area surface, adjustable interiors as well as simplified transport and relocation of the modules. According to the manufacturers, the total cost of ownership for a module is lower than the one of a competitive alternative over a lifespan of 15 years. Also, the buildings are meant to last for over a century if well maintained, and are designed to be highly energy-efficient. However, clients still often seem to opt for non-circular alternatives when it comes to the actual purchase.

This building was chosen because of its combination of modularity, the use of wood and its durability. For more information, see chapter 4.2 ‘Finch Buildings’.

Finding information about the building was not difficult, since there were several commercial reports available. However, detailed technical information as well as the barriers and enablers experienced by the company were not easily found. Our opinion is that in the future this kind of modular, flexible and sustainable buildings might have a significant breakthrough on the market if a successful marketing campaign is performed.

Pluspuu Talot

Pluspuu Talot is a studio founded in late 2009 in Helsinki, Finland. As their main product, they offer architectural services with house packages, consisting of carefully designed log houses in various shapes, making them customizable according to the customer’s needs. Their line of products is all based on wood, that compared to other traditional building material is renewable and combines characteristics such as insulation, ventilation and durability. Pluspuu Talot uses the manufacturing company Ollikaisen Hirsirakenne for the construction of the buildings. As the project customer from Novia’s R&D department showed interest in the circularity and the supply chain of the company, the decision was made to further research in the matter. For more information, see chapter 4.3 ‘Pluspuu Talot’.

Finding information about the company, their way of building and different technologies was not hard, as their website was packed with useful information. What was lacking was information about the actual circularity in a loop after sales, as in refurbishment plans and reuse of the materials, and the company didn't give any additional insight in the question. In the future we will likely see the company adding a refurbishment plan and maybe the implementation of recycled materials.

Villa Asserbo

Villa Asserbo is a '3D wood printed' house, located in Asserbo, Denmark. The focus of this project was to have the smallest possible environmental footprint for a building, in aspects such as designing, building, usage and deconstruction. The villa was build out of modular segments, made with a portable CNC-machine. The machine milled multiple digitally designed sections in quick succession, out of sustainable plywood boards. The modular segments are small and light enough to be carried by two persons, which makes heavy equipment redundant and on site building possible. The project was chosen because of its focus on circularity both in the technical and biological cycle. It also uses wood from the Nordic wood industry, and ample information was initially available.For more information, see chapter 4.4 'Villa Asserbo'.

Villa Asserbo is positioned in a suitable environment, both physically as well as economically. Denmark stimulates sustainable and energy efficient projects, with only the moist/ water control legislations impeding construction with wood. Information about the building was hard to find as it is a 'one of a kind', but the technology used was interesting, so we are surprised it did not receive more attention.

De Fire Styrelser

De Fire Styrelser, also called Nexus CPH on technical terms, is a hub for four Danish government boards located in Copenhagen, Denmark. The building is designed as a PPP (Private Public Partnership-project) meaning the responsibility of the building is for the builder, also called the contractor. The customer pays a fixed price for using the building, which stimulates the investment into efficient and durable systems and technologies from the contractor. The building is designed to be flexible, upgradable and durable. The building was chosen because of its form of agreement, which changes the common ‘owning a property’ to a leased construction and is one of the requirements for a circular economy. For more information, see chapter 4.5 ‘De Fire Styrelser’.

Denmark has a favourable geography, both physical as well as economically. The legislations stimulate energy efficient buildings, which helped making this building comply to the Danish 2020 energy requirements. We found the project to be what circular economy is about, and predict this kind of building agreements to be game changers in the future building industry.

Park 20|20

Park 20|20 is the first fully operational cradle to cradle work environment, with multiple buildings on an area of 114.000 m². The main focus, besides being cradle to cradle, is the well-being of its inhabitants. The business park incorporates different circular solutions such as buildings that are designed for disassembly, the use of solar panels, a 'closed loop' water-management system, green roofs and green walls. The business park was chosen for its use of C2C materials and the large scale of the project. For more information, see chapter 4.6 ‘Park 20|20’.

There was a lot of information on Park 20|20 available, however like in the case of Finch Buildings, detailed technical information was not available online. Park 20|20 was not available to consult for further information due to other priorities at the moment. We reckon the park will be successful, while its technical solutions will hopefully spread to less high-end projects.

Bionorica Headquarter

The Bionorica Headquarter is situated in Neumarkt, Germany, and is a building planned to be fully recyclable. Special about the building is the supply chain, as the materials that cannot be recycled, like windows and carpets, are taken back by the supplier through a leasing agreement. What is also outstanding are the technical solutions implemented in this building as it is PVC-free. The roof and part of the façade are made out of solar modules, which produce more energy that the building actually consumes. For better thermal insulation, green façades have been installed enriching the air with oxygen and reducing carbon dioxide content. The building was chosen for the implemented technical solutions as well as its circular supply chain. For more information, see chapter 4.7 ‘Bionorica Headquarter’.

There was a lot of information available on the internet, mainly on German websites. Since the building is already ten years old, it was a milestone in CE-inspired buildings by that time. In general, Germany does not specifically promote circular economy in the construction industry, but supported the use of solar modules in house building. We hope more of this kind of buildings will be designed in the future, while at the same time we find it strange that leasing of the materials and parts has not yet made a leap forward into the commercial housing market.

5.2 Future research

For further research by the R&D team of Novia UAS, or by anyone performing such a task in the field of CE in the construction industry, here are some thoughts and recommendations on the topic presented. For the research process of existing CE buildings, projects or companies we highly recommend knowledge of the local language, as information and sources are significantly easier to find. Online information is sometimes lacking, so by contacting involved parties one can find out information not available before, as well as saving precious time and resources.

Several documents that handle specifically about CE in the construction industry where found online and can be useful for further research. One specific document highlights several CE-examples in the building environment and key principles, which are based on the ReSOLVE framework by the Ellen MacArthur Foundation. The title is “Circular economy in the built environment” made year 2016 by ARUP, a global independent company of specialists. The link is the following:

https://www.arup.com/publications/research/section/circular-economy-in-the-built-environment

Building up clear guidelines and a structure is recommended, in order to make the research topics better comparable, highlighting their differences, pros and cons. Using guidelines and a structure also helps being time effective, having a clear aim on what to look for.

We hope that the information in this document helped taking society one step closer from linear to a circular, sustainable economy.

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