

The circular supermarket chain

Introducing the Circular Economy in the
Building Specification



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PREFACE

During my study Architecture at the TU Delft, we were confronted with the integration of sustainability in our designs. It showed many possibilities for adding sustainability to a design, there is a lot of room for experimentation and a student's individual views and knowledge on the matter. The focus of the sustainability in the building industry is applied in bachelor projects primarily through the use of renewable energy sources. This sustainability is often achieved through the addition of solar panels or wind turbines to one's design. Another view often employed is the sustainable function of a design, allowing functionality to change along with its occupants. Allowing change by making a structure transformable or modular. Still the overall view or philosophy why a sustainable choice is 'right' is difficult to describe. These choices are usually added as loose components, trying to bandage and staple sustainability to a design, which is primarily focussed on an aesthetic concept instead of a complete view on the sustainability. For projects which actually have sustainability as a focus, it's difficult to say 'why' you actually add sustainability. Preparing for the future generations, making sure they aren't stuck with problems we caused through our consumption. This is one of the most coined reasons for 'why' we should build sustainably.

In the masters Building Technology the term Circular Economy came in play. From my point of view, it provides a good explanation on why sustainability is important, and especially how all the sustainable choices intertwine. I found it interesting as it provides a vision on which you can base your design choices. It's an ideology which shows how not much has to be changed to become sustainable, it shows that it doesn't have to be more expensive either. The Circular Economy interested me in many aspects, as it's a subject which covers many different specialities. Design, engineering, management and chemistry, are just a few which all have their influence on the Circular Economy. The philosophy behind the Circular Economy has been around for a multitude of years, its actual implementation hasn't had a large uprising yet. This opens up many interesting aspects which can be researched.

The Lidl approached the TU Delft with the question if they could assist them in making the building stock and their operations circular. With this they opened their doors for graduation projects into their supermarket chain. For me this was an interesting opportunity, a theoretical approach with lots of research options applied to a practical, large scale, case. Though I had heard about the Circular Economy, often I had no real grasp of what the actual principles and vision of it was. This was the perfect case to experience the interpretation and the implementation of the Circular Economy first hand, see what is already known and if it's feasible to apply to an existing company.

The result is the report in front of you. It gives an insight in the measurability of a circular design, an assessment of where the Lidl is currently on the circular approach. It also shows that, for assessment, there still is a long way to go until we are able to fully compare products and designs. The report shows which choices can be made to design for circularity. Lastly it shows how the principles and ideas can actually be implemented, in the Lidl's building strategy and their Specification.

ABSTRACT

The main question of this master thesis is: Which changes have to be made to make the Lidl's Specification circular, with an emphasis on materials and assembly? To come to an answer, a multitude of steps were taken.

The first step was an assessment of the principles of Circular Economy, the principles which lie at the foundation of the, Technological and Biological cycle. A number of different assessment methods were analysed on their circular implementation, they have been evaluated on five assessment criteria for the Circular Economy. The Material Circularity Indicator and the Disassembly Potential are concluded to be the most effective, especially when used in tandem. The Material Circularity Indicator is used to determine the circularity of a material used in a building component. The Disassembly Potential gives an indication how well a building can be brought back to its original materials, it determines if disassembly or demolition will be most likely. These two methods used for the next step.

This next step is the analysis of the Specification of the Lidl. The 6 S-model of Steward Brand is used in combination with both the MCI and the DP to determine the circularity of the most important components mentioned in the Specification. The components are divided into three categories, sufficient, partially sufficient and insufficient in their circularity.

As the third step, a redesign was made, to change a component from insufficient to sufficient. The roof was chosen as this component. Most of the roof components were partially sufficient, but has a lot of functionalities, which make it a broader applicable example.

In the redesign, two design were evaluated, a technical redesign and a green redesign. The technical design mainly focussed on rematerializing the original roof design so it would receive a higher MCI, the result showed that just changing materials isn't a sufficient strategy, the design needs to enable disassembly. The green redesign instead focussed on used biological degradable materials, it fully redesigned both the materials and the connecting principles. The green redesign showed which changes were necessary to enable circularity in the Specification.

Each of the steps provided answers to main research question. The result are the following five changes:

- Exchange non-circular materials, materials which can't be economically recycled at the end of their technical life span, for materials which can be recycled.
- Enable reuse of materials, by removing static constructions methods, making all connections reversible.
- Make dimensions and connections generic.
- Implement the criteria from the Material Circularity Indicator to the Specification for circular materials.
- The development strategy of the Lidl needs to be changed, reusing elements and components instead of employing new ones.

These recommendations are a reasonable first step on a long journey to a circular supermarket chain.

Key words: Circular Economy, Specification, Bouwkundig Bestek, Material Circularity Indicator, Disassembly Potential, supermarket

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1 INTRODUCTION

There are many interesting challenges that can be examined and researched within the Lidl's built environment. First the challenge will be described in the problem statement. Next the research question will be described to provide a possible solution, this will be done through sub questions. The next step is determining the methodology and framework in the research design. Last step will be the expected results and the usefulness for the Lidl.

1.1. Problem statement

The building industry, within the Netherlands alone, is responsible for 26 billion kg of waste a year. They are responsible for over 50% of the total annual waste of the Netherlands (Rijksoverheid, 2017(1)). The Lidl opened its first store in 1996 in the Netherlands, in 2018 this number rose to over 415 stores in the Netherlands (LIDL, 2017(2)), they plan to keep on expanding for the upcoming years. Due to them being in a fast changing market they renovate their stores every eight years to be able to keep up with consumer demands. In the Dutch retail industry buildings have a general lifespan of 20 years, before needing a renovation. After that renovation becomes a necessity (Zabalza Bribian, Valerio capilla, & Aranda Usón, 2010). Attempts have been made to improve the sustainability of the Lidl stores. The Lidl tries this by having a A++++ grade on their buildings (LIDL, 2017), BREEAM grades on new structures like the distribution centre (BREEAM NL, 2012) and changing their construction principles and materials (Viereck & Graz, 2016). All these methods provide different means and views to improve their level of sustainability. Lately the interest in the Circular Economy has been on the rise, providing incentive to approach sustainability and construction from a different point of view. The difficulty with the Circular Economy is the methods to measure and compare your buildings and constructions to others. While the principles are known the actual assessment methods are still being developed as shown by examinations of the current assessment methods (Elia, Gnoni, & Thorese, 2016).

For the Lidl, with such a large portfolio of real estate, it provides multiple questions, how circular are we now? Where do you measure it? How do you measure it? The first question should be examined on the most basic level. How circular is our current building vision? It's difficult to comprehend which changes have to be made if you don't know what your starting point is.

1.2. Research questions

As stated before, with a new subject like the Circular Economy, it's difficult to understand where you stand currently as a company. On the subject of circularity in the built environment it's necessary to take a first step to examine the current practices used. One of the most complete documents available on the current building philosophy is the Lidl's Specification. This document provides insights in: materials used, involved actors, the responsibilities of these actors, assembly methods and assembly sequence. All these factors are fundamental for the Circular Economy. Through these notions the main research question arose:

Which changes have to be made to make the Lidl's Specification circular, with an emphasis on materials and assembly?

Before we are able to answer the main question, the need arises to answer a set of sub-questions first, each providing a step towards the conclusion for the main question.

- What are the principles for circularity in the built environment?
- How is the Dutch Specification currently implemented?
- What are the current methods to assess the level of material and building circularity?
- What are the circular bottlenecks in the current Lidl's Specification?
- How can a building system, as described in the Specification, be redesigned into a circular one?
- Which changes have to be made to the Specification to allow for the redesigns to be implemented?

These questions will be answered through the following research methodology:

For the first sub-question, the core principles for circularity in the built environment have to be determined. Through a literature study into current reports on circularity, the current definition for circularity will be formulated along with the principles for the Circular Economy. The application of these principles in the built environment, along with the consequences, will be examined. The same has to be done for the Specification. Before we are able to look in-depth into the Lidl's Specification, we have to examine how the current Specification is used and defined in the Netherlands. This will be examined through government sources, books, and further literature. For the assessment method, multiple papers and thesis reports into currently used assessment methods will be consulted. These will be used to examine assembly methods and materials used. The NIBE database will be consulted as the database for material properties.

With these assessment methods and the current use of the Dutch Specification in mind, the Lidl's own Specification will be graded and where needed Lidl sources will be interviewed for additional information. It will result in one of three grades, a part is circular enough to be sufficient for the time being, a part can be made circular with few changes, or a part has to be redesigned completely with different materials and connections. Where needed, any material suppliers will be interviewed on material life-cycles. The NIBE database will be used to find circular solutions for materials. As a final step the redesigns will be re-implemented into the Specification, along with additions on circular grading method and policy to make them persistent.

1.3. Expected results

The Lidl will receive the following results in the report:

1. A circular assessment method based on contemporary methods.
2. Analysis of the Lidl's Specification on circularity.
3. Recommendations for additions to the Specification.

With these the Lidl can determine their own approach towards the Circular Economy. It provides them with the knowledge to make an educated guess on their current standing on circularity in the built environment and to assess proposed solutions.

1.4. Report structure

The report itself will contain three distinct parts. Each containing two chapters which relate directly to the sub-question. The first part contains the outlines, it'll assess the foundations for the report. It contains chapter 2, the principles for circularity in the built environment, and chapter 3, the current implementation of the Dutch Specification, .

Part two of the report will contain the analysis of Lidl's current Specification. It contains chapter 4 which relates to the current assessment methods on circularity. 4.1 examines the current used assessment methods on circularity, 4.2 will describe how the equations of the MCI are structured and how the method can be applied and 4.3 which deconstructs the Disassembly Potential. The second chapter in this part, chapter 5, will apply the principles of the Circular Economy and the assessment methods to the Lidl's current Specification, providing an overview on the level of circularity

The third and final part is on the redesign and rewriting of the Specification. Chapter 6 examines and redesigns the current roof design. 6.1 examines the current roof and shows which parts have to be changed to allow it to be circular. 6.2 is the blue proposition, this will stay closest to the original design. This redesign will change as few materials and connections, the idea of the roof structure should stay the same but with an higher MCI and DP. 6.3 is the change from a roof consisting mostly out of technical materials towards the biological materials. The seventh chapter shows how the Specification and the Lidl itself have to be changed to allow for these redesigns and ensure their circularity during realisation. This will provide the answer to the final sub question and the research question. These two will be concluded in the final chapter, chapter 8.

2 WHAT ARE THE PRINCIPLES FOR APPLYING CIRCULARITY IN THE BUILT ENVIRONMENT?

It's debatable who first coined the term Circular Economy and also when the philosophy started, as determined by the report from Winans, Kendall and Deng (2017). Its origins and interpretations are vague and have been in a state of change since 1990. Though the subject gained more traction in the past few years, it didn't receive a single definition. Research pointed out that there currently exist over 114 definitions for the Circular Economy(CE) (Kirchherr, Reike, & Hekkert, 2017). Each with a multitude of principles. There has been research which state there are 3R's(Reuse, Reduce, Recycle)(Winans, Kendall, & Deng, 2017) at the basis up to 9R's((Potting, Hekkert, Worrell, & Hanemaaijer, 2017).

2.1. Definition of the Circular Economy

The foundation for our current linear economy is based in the early days of the industrialisation. This model ensured cost decreases through optimization and efficiency increases in the production process. Often this model is referred to as the take-make-dispose model. Four steps are usually applied in production processes that rely on this model: resources are harvested, a company implements labour and energy to manufacture a product, the product is sold to a consumer and when the product is no longer of use it is discarded (Ellen MacArthur Foundation, 2013).

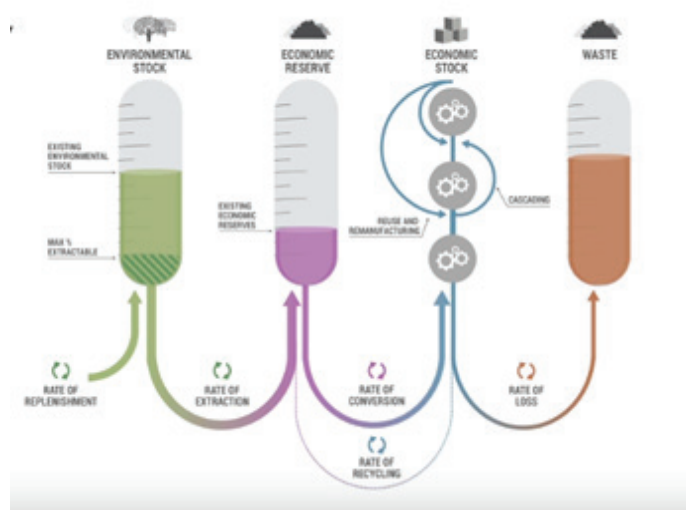


Fig. 1: Linear economy – (Gladek, 2016)

Over the years, the amount of raw resources consumed through this linear model rose significantly. What was 65 billion tonnes of raw materials in 2010, is expected to grow to about 82 billion tonnes a year in 2020. Though the linear model provided optimization and efficiency increases in the production process, producers are noticing an increase in risks over the years. Resource prices have become more volatile, while competition has been rising and demand for the products has been stagnant.

These risks have erased a century worth of price reduction, achieved through the optimization of the industry. This all happens while resource extraction costs rise and easy attainable resources get depleted (Ellen MacArthur Foundation, 2013).

The response to this linear economy, with unrecoverable waste as its largest output, has been the Circular Economy. As stated in the introduction, there is a multitude of definitions for the Circular Economy, each with its own principles, as shown by Kircheherr, Reike and Hekkert (2017). The most used definition in the 148 articles they examined, though it's only used directly eleven times, is the one supplied by the Ellen MacArthur Foundation. All other definitions are slightly different when compared to each other. This amounts to an eventual 103 different definitions for the Circular Economy. The definition provided by the Ellen MacArthur Foundations (2013, p7.) reads:

“An industrial system that is restorative or regenerative by intention and design. It replaces the ‘end-of-life’ concept with restoration, shifts towards the use of renewable energy, eliminates the use of toxic chemicals, which impair reuse, and aims for the elimination of waste through superior design of materials, products, systems, and, within this, business models.”

They describe the Circular Economy in three principles, which can be applied on all levels of the economy(Elle MacArthur Foundation, 2017):

- 1 Design out waste and pollution. All negative externalities need to be exposed and resolved. Toxic substances, Greenhouse Gasses and all other kinds of pollution need to be addressed and eliminated.
- 2 Keep products, components, and materials at their highest value and in use. This principle is based on the 3R's. The MacArthur Foundation uses the 3R's, Re-use, re-manufacture, and recycle. This principle is what gives the CE its circularity. Which will be described in the next chapter, as the four powers and value gains.
3. Regenerate natural systems. Making use of the natural capital instead of the finite resources, promote this natural capital everywhere by allowing it regenerate, providing soil and nutrients where needed.

These three main principles lie at the basis for the CE, they are usually described in figure 2. This figure describes the Power of circling, which is brought forth by the implementation of the Circular Economy. In the diagram our resource use is divided into two flows which need to stay fully separated. Both these flows, while being circular, have a multitude of different characteristics. The CE provides value through four types of cycling.

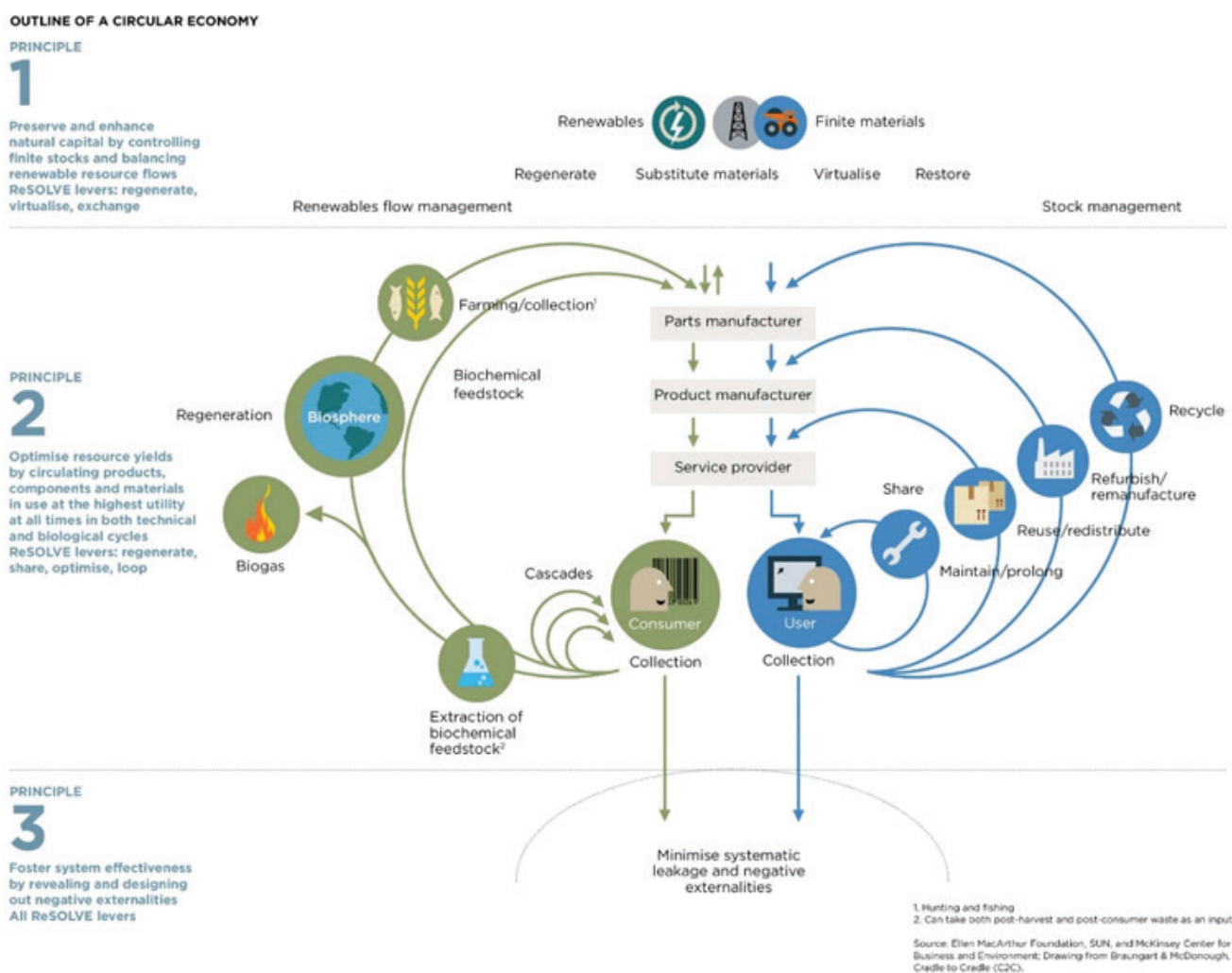


Fig. 2 The Circular Economy - an industrial system that is restorative by design(Elle MacArthur Foundation, 2013)(p.25)

Power of the inner circle: The tighter the circle, the larger the savings and the longer you can extract value from your product. By keeping the circles small you can save on labour, energy, materials, and capital, while avoiding extra externalities. Re-using your product, which may only require small maintenance, is always a cheaper, with the right design, and faster than making the product from scratch.

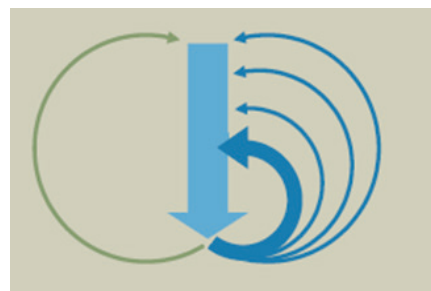


Fig. 3 : Power of the inner circle(Elle Macarthur Foundation, 2013)(p.31)

Power of circling longer: A product can be used to its full potential. The use life cycle rarely matches up with the technical life cycle of a product. The product, components, and materials stay longer in use. Instead of producing new products, which requires a virgin material influx, the same product is used. This power is made more attractive in areas where resource prices are rising rapidly. This lever increases operation and maintenance costs through its longer life cycle, and you may be losing out on efficiency gains through rapid innovations. These factors could negate the gains and positives.

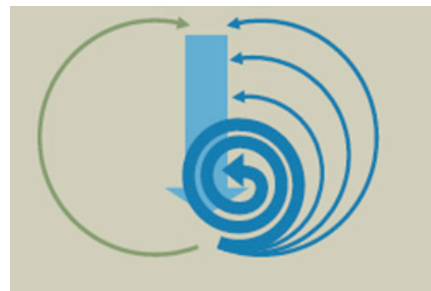


Fig. 4: Power of circling longer(Elle Macarthur Foundation, 2013)(p.31)

Power of cascaded use and inbound material/product substitution: This principle applies more to the biological side of the model. The previous creations of value were about an identical product, where materials and maintenance would result in the exact same product each time. This flow applies to materials that lose value over their life time. These materials should be completely avoided in the technical cycle, but is inherent to the biological cycle. While the material loses value over time and becomes obsolete for a certain function, it might be of right value for a different function. For example cotton based clothing is turned into filling for furniture, then it's turned into insulation material before being composted and returned to the biosphere. It provides value for both functions. This enhances the life expectancy of the material and allows the already embedded costs of the waste material to be used.



Fig. 5: Power of cascaded use and inbound material/product substitution(Elle Macarthur Foundation, 2013)(p.32)

Power of pure, non-toxic, or at least easier-to-separate inputs and designs: This last power is to enhance the value creations provided by above mentioned principles. It ensures both the technical and biological cycle stay separated. When biological materials become toxic, they can't return to the biosphere. Instead they end up as waste or are incinerated, which releases the toxicity into our environment. To be able to keep the value creations above working, a purity of materials is needed. By allowing products to be stripped to their basic materials, costs for separation and contamination will be avoided. Through this materials retain their value. It allows the materials to re-enter the system quicker. It provides longevity for materials through prevention of down-cycling. This would make it possible, on a theoretical level, for technical materials to be used infinitely.



Fig. 6 : Power of pure, non-toxic, or at least easier-to-separate inputs and designs(Elle Macarthur Foundation, 2013)(p,32)

The three principals, the 3R's, at the core of the CE can be translated into six business actions, the ReSOLVE framework(Ellen Macarthur Foundation, 2015a). These six actions are as follows:

Regenerate: Transition towards renewable energy and material sources. Sources extracted should return to the biosphere.

Share: Optimize products used by sharing them with different users, ensuring a smaller pool of products needed for the same client base.

Optimise: Improve efficiency and performance of your product, by applying new technologies of data gathering and analysis. No changes to the product are needed, just changes to the information model.

Loop: Keep products, components and materials in smallest loops as long as possible.

Virtualise: Products that don't need to be physical should be supplied through a virtual medium. Books, virtual offices, virtual shopping.

Exchange: Use technologies and advancements in science by updating materials and exploring new possibilities.

2.2. Implementing the principles in the built environment

While the philosophy of the CE has been around for a few decades, the implementation into the built environment is still in its infancy. There are two interesting points for applying the CE to the built environment (Pomponi & Moncaster, 2016). The first point is that the life cycles within the built environment are longer than in most other industries. Studies show that out of the buildings currently around, most will be around, in some shape or form, for the next 60 to 90 years. On a second note, while most buildings use well known standardised products, the way they are combined differs for each building, which makes each building and assembly unique. Steward Brand described this combination of products in his book 'How buildings learn' (1994), he called them the shearing layers of change. These layers usually have different life cycles, and when locked together they will tear the building apart once one of the layers becomes obsolete. The Circular Economy can be enabled on a multitude of levels within the building sector. It can be applied to the building as a whole, the components, the products and even in the design stage (Adams, Osmani, Thorpe, & Hobbs, 2017).

The complex nature of the building industry makes it difficult to pinpoint all aspects on which the Circular Economy can apply, this makes it difficult to directly apply the ReSOLVE framework. The Ellen MacArthur Foundation described how each of the part of the ReSOLVE framework can be applied to the built environment (Foundation, 2016):

<u>Regenerate:</u>	Use renewable energy sources for you buildings, apply resource recovery and produce renewable energy in your building (electricity, hot water, bio-gas).
<u>Share:</u>	Shared water consumption, shared office, Co-housing.
<u>Optimise:</u>	Use prefab construction methods, energy efficiency, water efficiency, material efficiency (re-use, renewable materials, recycled, recyclability, lower carbon footprint, etc.).
<u>Loop:</u>	Optimise and examine the end of life of buildings and materials, add modularity, disassemble and re-manufacture materials.
<u>Virtualise:</u>	Virtualisation of products, virtualisation of the processes used, smart systems (data driven energy and heating systems).
<u>Exchange:</u>	Use materials that preform better, apply advanced technologies, use new products and services.

2.3. Conclusion

With the Circular Economy gaining traction over the years it has gained a multitude of different definitions. While the principles applied are usually comparable it's important to outline 'your' definition of the Circular Economy to prevent miscommunication and differences in expectancies.

“An industrial system that is restorative or regenerative by intention and design. It replaces the ‘end-of-life’ concept with restoration, shifts towards the use of renewable energy, eliminates the use of toxic chemicals, which impair reuse, and aims for the elimination of waste through superior design of materials, products, systems, and, within this, business models.”

The definition employed within this report is defined by the Ellen MacArthur Foundation:

These lead back to the three main principles in the Circular Economy:

- Design out waste and pollution
- Keep products, components, and materials at their highest value and in use
- Regenerate natural systems

By employing these principles we can shift our economy from the Linear to the circular model, this shift doesn't have to cost companies extra. It's meant to extract the full value out of every product and material. Unlike our current system, where products are thrown out before their useful life ends. This is just one of the four powers provided by the Circular Economy.

Still another step is needed, as the building industry differs from many others. Components and materials in the building industry, already function much longer than many other products. They are combined into composite structures where they don't function on their own but become part of an integral design. The building industry can implement the Circular Economy on many facets. Through the aspects in the ReSOLVE framework points of interest are given. The ones which will be focused on in this paper are within the Regenerate, Optimise and Loop. The focus lays on the Materials and connections.

3 HOW IS THE DUTCH SPECIFICATION CURRENTLY IMPLEMENTED?

The Dutch specification is a set of guidelines which were introduced in 1989. These guidelines were introduced to streamline the contracts between client and contractor. Due to the many different iterations it was difficult to comprehend everything written down. The guidelines were introduced to reduce the amount of errors in communication. As a client you are still allowed to write your own Specification, put anything in it that you deem necessary. The Specification is both the contract and the tender, a document containing all information necessary to realize the building.

3.1. Implementation of the Specification

In the Netherlands the Dutch building process is a linear process, made up of four steps. Each of these steps is divided into phases and sub phases. The first step is the Initiation, followed by the preparation, realisation and use. As described in the figure below, the seventh sub phase is the Specification.(Wamelink, 2010).

Sub Phases	1. Initiatif	2. Attainability study	3. Project definition	4. Concept design	5. Preliminary design	6. Final design	7. Bestek	8. Price negotiation	9. Work preparation	10. Realisation	11. Finished product	12. Maintenance	13. Demolition
Cycles	Initiation			Preperation			Realisation				Use		

Fig. 7: phases in the building process (source: own image)

In 1989 the ‘Uniforme Administratieve Voorwaarden’, or UAV in short, were introduced in the Netherlands. These were a series of guidelines introduced in the building industry. This way clients and contractors didn’t have to reinvent the rules for every project(Wamelink, 2010). Over the years slight adjustments have been made to the rule set. The last changes have been implemented in the year 2012, in that version the definition for Specification is described as:” de beschrijving van het werk, de daarbij behorende tekeningen, de voor het werk geldende voorwaarden, de nota van inlichtingen en het proces-verbaal van aanwijzing;”(Spies & Verhagen, 2012).

Due to the complexity of a building and the many parties involved, it is important that the information is transferred in a clear way to avoid uncertainties. The drawings are only part of the Specification, most is done through text. There used to be a multitude of different standards for the Specification, these days the most used standard is the so called ‘STABU-Bestek. This, on top of the guidelines in the UAV, allowed for further standardisation, which allows for a clearer description for the multitude of actors involved in the realisation of the design(Wamelink, 2010).

The Specification is usually build up from two parts, the general description and the specific description. These two are usually divided on their work theme: concrete, woodwork, bricklaying, etcetera.

3.2. Value versus Price

The Specification is, in first instance, the tender on which contractors can bid, then it becomes the contract that binds the client and contractor. This bidding allows a fair choice of contractor and allows the competition to lower the price. This leverage of competition gives the client an interesting conundrum. Do you specify all materials and assembly sequences so you know exactly that your specific project is built? Or do you just give general performance indicators? The first reason to allow for a less specific Specification, it allows the contractors to each supply different solutions, this broader view usually results in a lower price. The second reason why a less specified Specification can give interesting results that it allows for innovation, newer materials can be used that the architect might not have heard of. As a third reason you are able to use the knowledge of different contractors. Each contractor has his own suppliers, each with their own knowledge on new and innovating technologies and products. This can provide extra value for the client(Dreschel, 2009).

Not always will the cheapest bid win, the relation between value and price is important. You want your value to be more than your price, when this value is less than your price, you're losing out. Though to determine what actually the value is, is difficult(Dreschel, 2009).

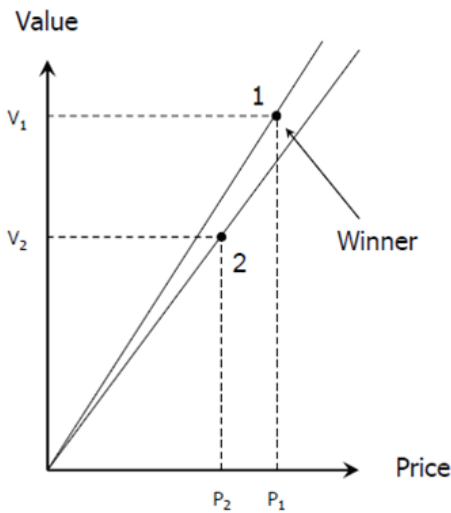


Fig. 8: Choice of contractor based on value versus price(Dreschel, 2009)

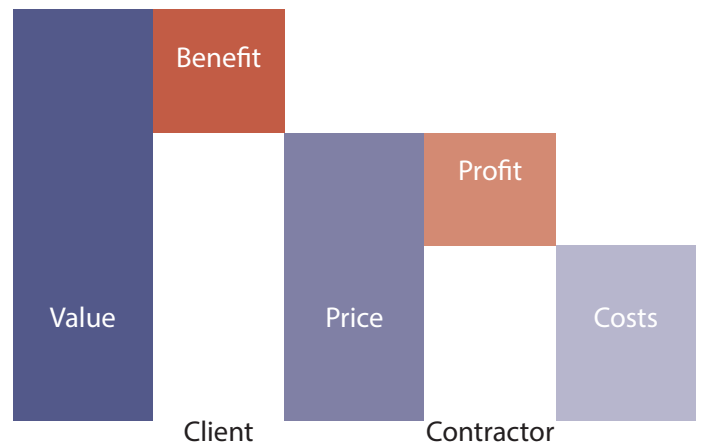


Fig. 9: Comparing value to price (source: own image)

This definition for value can differ from one client to another. For some clients sustainability is important, to others durability or aesthetic might be one of the value's

According to an article in the Dutch building magazine "Roofs", the Dutch Specification has a few inherent issues. The Specification is usually constructed in parallel to the technical drawings. This means that not all changes in the drawings are incorporated in the Specification. In the Specification, there is usually just a RC value given for a insulation material, this requires the contractor to make all the calculations on his own. There is a mismatch between what the designer usually wants and the technical knowledge needed to actually create the design. The Specification is a collection of many different professions. Another issue is that the contractor doesn't need to use the specified material, he has the right to use comparable materials(van Scheijndel, 2007). This is described in the Specification with the letters o.g., which stands for 'of gelijkwaardig'. This allows the contractor to choose a similar material or component. As the article describes, it's a lot more difficult to provide a definition for a comparable material. It's not difficult to look at the technical specifications, but issues start to arise when the norm is significantly lower than the materials requested in the Specification.(van Scheijndel, 2007).

3.3. Conclusion

The Specification is an interesting part in the Dutch building industry as it is the key component between drawings and design and the actual realisation of the building. This is also what makes it an interesting object to examine Lidl's building strategy. It contains everything that needs to be known to complete the supermarket design. It contains the drawings, materials, connections, calculations, suppliers and obligations.

It's a juridical document, everything specified in it can be used in court when mistakes are made. Next to that it's also a tender, to which contractors can apply in hopes of besting their competitors. This makes it on one hand important that everything is fully specified and can't be misinterpreted, but on the other hand leaves enough room for the contractors to use their knowledge of the construction market.

There is an interesting dynamic between the contractor and the client. The client wants to get as much value as possible for the lowest price. It is difficult to determine what the value is, as value is a different concept to each client. For the Lidl it could be any number of things, for the Lidl a high score on the circular assessment methods could be a factor to measure value.

4 WHAT ARE THE CURRENT METHODS TO ASSESS THE LEVEL OF MATERIAL AND BUILDING CIRCULARITY?

The Circular Economy (CE) isn't a necessarily new approach, it was already applied in Germany in 1990 and describe by Rachel Carson in 1970(Winans, Kendall, & Deng, 2017). In the last few decades the CE has been reviewed, analysed and used in multiple frameworks and even production strategies. One part of the CE has been touched on by few scientific sources, this part is the assessment method, how do we measure the CE (Elia, Gnoni, & Thorese, 2016)? This makes effective comparisons between strategies and designs difficult. Quirine Henry made, in her report, a comparison between five assessment methods that are currently used(Henry, 2018). The examination done by Quirine is taken a step further, the eventual methods chosen are laid out and show there is still room for improvement.

4.1. Assessment methods analysed

In her paper she examines: the Life Cycle Assessment (LCA), Material Flow Analysis (MFA), Longevity Indicator (LI), Material Circularity Indicator (MCI) and the Disassembly Potential (DP). The assessment methods are examined on their inclusion of five principles which lay at the basis of the Circular Economy. Through these principles you want to be able to see and promote the influence on (Elia et al., 2016):

- Reducing the input and use of natural resources.
- Reducing emission levels.
- Reducing valuable material losses.
- Increasing share of renewable and recyclable resources.
- Increasing the value durability of products.

This analysis of the assessment methods results in the following figure, as can be seen none of the assessment methods cover all the factors except for the Disassembly Potential.

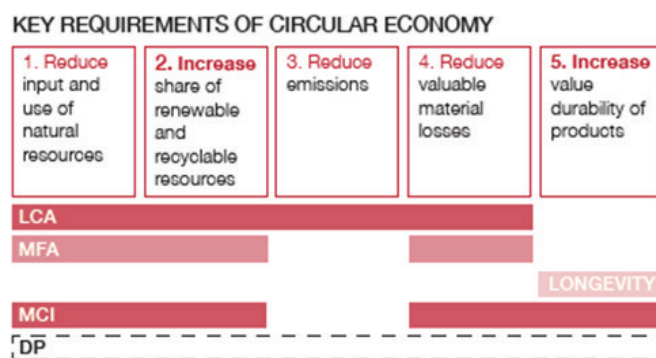


Fig. 10 Fig. 10: Key Requirements of Circular Economy (Henry, 2018)

Out of the four other methods, the LCA and MCI cover most principles. DP, though it covers all five principles, is different from the other methods. The DP influences all five principles indirectly, it doesn't provide concrete measurements of the five principles. Quirine uses a combination of the MCI and DP for her further assessment method. There are multiple reasons why the MCI instead of the LCA is used. The main difference between the two, besides the principles they cover, is the focus. The LCA focusses on the life cycle of a product in a multitude of scenarios, the MCI concentrates on the flow of materials through the use of the product. The MCI encourages the use of recycled and reused materials and recycling and reusing the materials again at the end of use. The input data for both the MCI and LCA overlaps on many fronts (Ellen MacArthur Foundation & Granta Design, 2015b). The LCA is an inherently linear assessment method, this provides a certain bias. The additional issue with the LCA is the amount of data and knowledge needed of the whole industry before being able to employ the method (Zabalza Bribian, Valerio capilla, & Aranda Usón, 2010). It's a very circumstantial approach as the inputs can differ, even if the supplier is the same, per production site. None the less, the lack of the inclusion of the emission assessment in the MCI results in a gap in knowledge, which is noticeable in the results, as both renewables and emissions are missing the results should be taken with a grain of salt. The LCA can still be used to fill this gap in future, though a new approach is needed for this principle (Henry, 2018). The next step before being able to use these assessment methods we need to set out how they are constructed.

4.2. Material Circularity Indicator

The MCI is still under development and can be expected to receive additions during the upcoming years. The MCI is specified towards the technical cycle. The biological cycle is not integrated yet, this makes it still difficult to compare technical solutions to biological ones. This effectively eliminates half of the concept of the Circular Economy, the adaptation of renewable materials. There aren't great indicators for grading renewable sources. The MCI is built up from multiple equations, each connected to a calculation step. This provides an insight in the circularity of your product on a material level. For the calculations the following inputs are required.

- Input in the production process: what are the sources for the feedstock, how much of that feedstock is from recycled and reused sources?
- Utility during use phase: how does the use phase compare to industry average of the same type of products?
- Waste scenarios: how much of the material will be recycled or reused?
- Efficiency of the recycling process.

The recycling and reuse inputs both aren't determined by theoretical recycling potentials but already existing recycling flows. The recycling and reuse are highly dependent on material value. While for most material a theoretical recycling process exist the process isn't necessarily economical, resulting in the material being discarded (Min & Galle, 1997). All these inputs combine to the following flow diagram. The result of these inputs is the Material Circularity Indicator, a grade between 0 (fully linear) and 1 (fully circular). It allows for the comparison of multiple design solutions (Ellen Macarthur Foundation & Granta Design, 2015b).

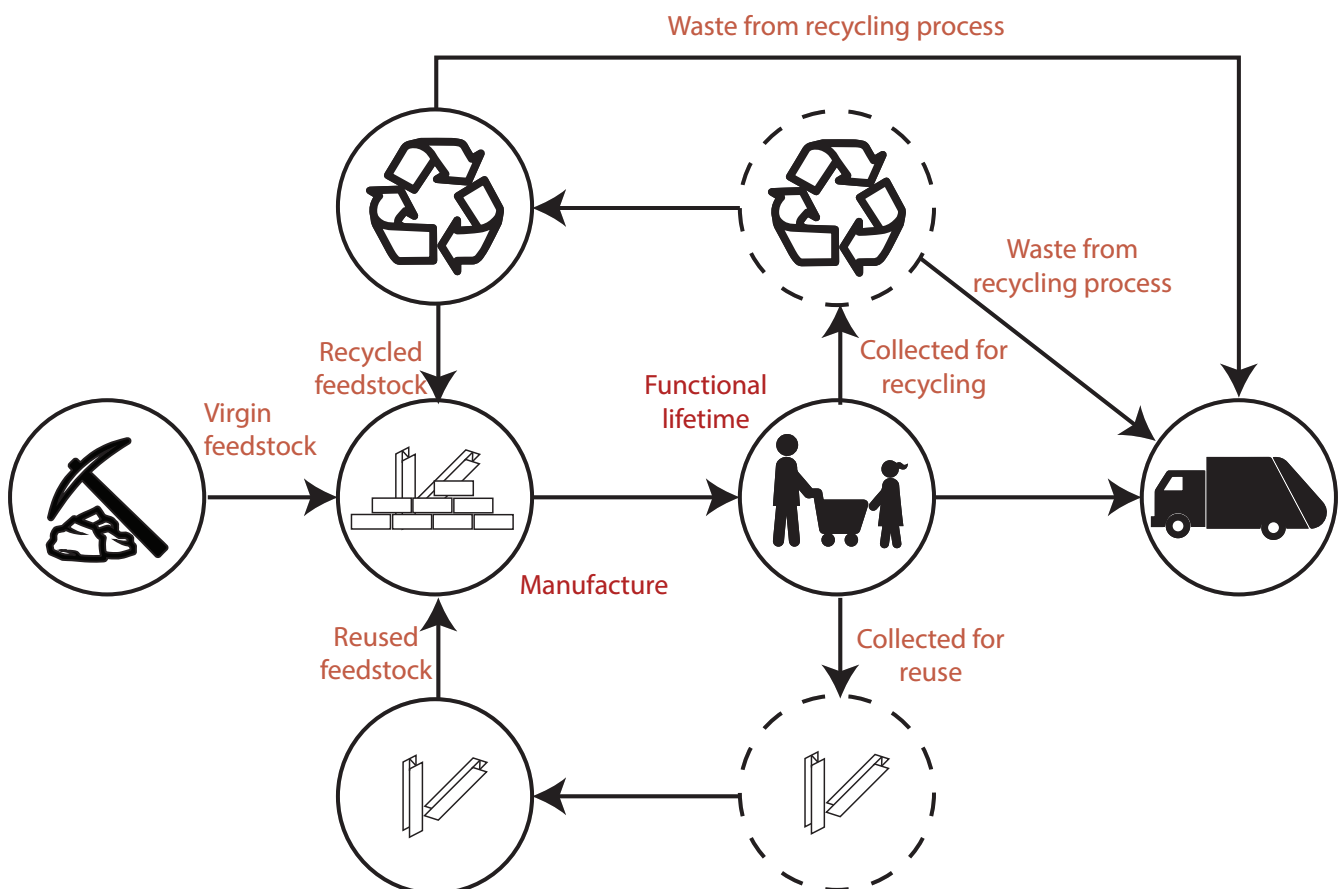


Fig. 11: MCI flow model (source: own image)

The MCI is obtained through a five step calculation process which provides interesting knowledge and insights about your product. With these you can calculate the following data:

1. Calculate virgin feedstock
2. Calculate unrecoverable waste
3. Calculate the Linear Flow Index(LFI)
4. Calculate the Utility Factor (UF)
5. Calculate the Material Circularity Indicator

These calculations are constructed through the following equations. These are all derived from the paper published by Ellen Macarthur Foundation and Granta Design(2015).

Step 1 Calculate Virgin Feedstock

For the MCI it is important the know the material sources of your product. This is the first step in the five equations, it looks at the material inputs in your system. The step is summarized in the following equation:

$$[1] \quad V = M (1 - F_R - F_U)$$

In which V is the amount of Virgin Feedstock [kg], M is the mass of the product [kg]. For the amount of the product that is from recycled or reused sources, it's described as a fraction of the total mass, which results in the equation $(1 - F_R - F_U)$. In this F_R is the fraction from recycled sources and the F_U is the fraction from reused sources. The correspond to the first part of the diagram. The summation of these two fractions can never be above 1, as this would result in a product containing more than 100% resources.

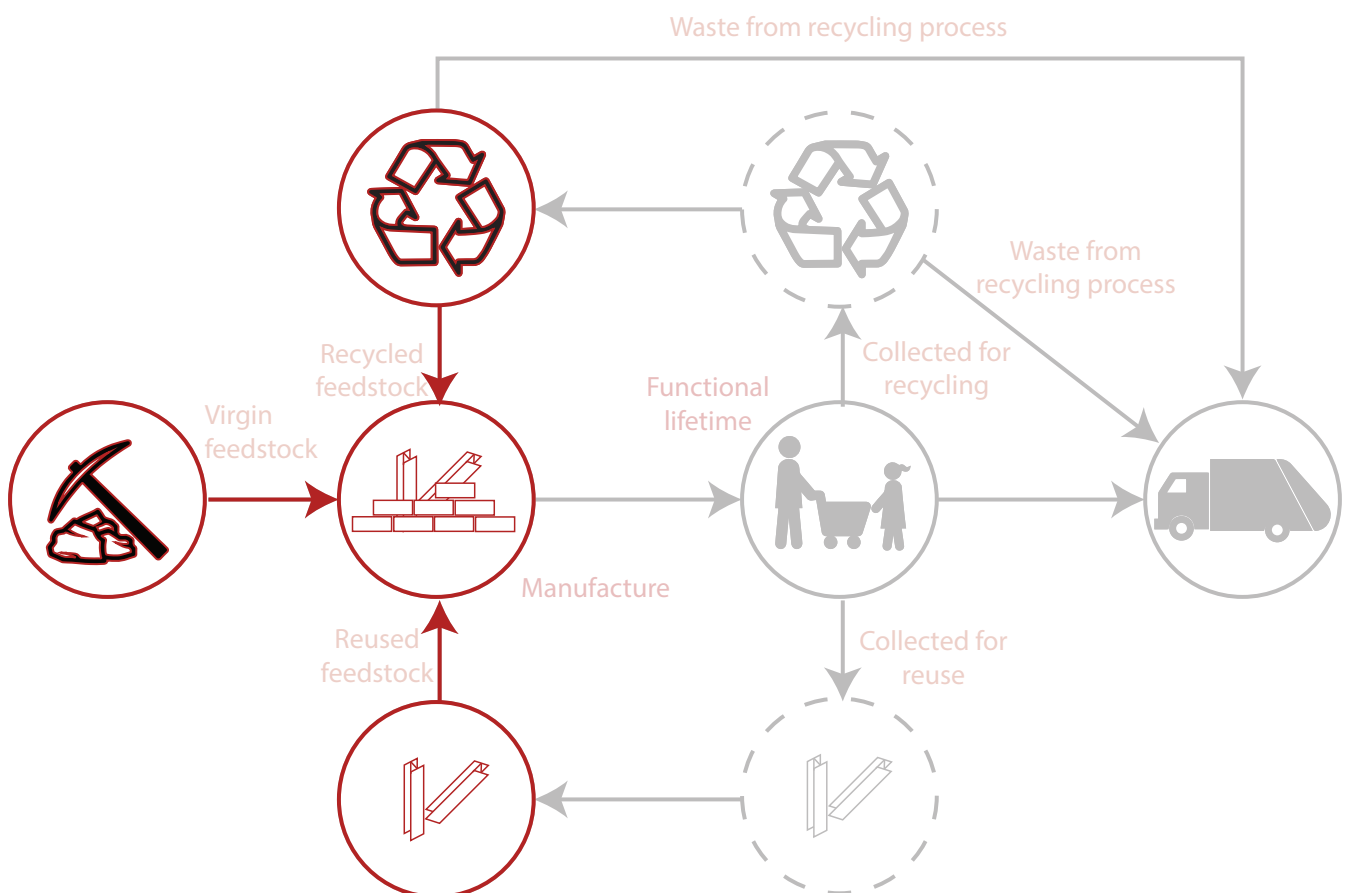


Fig. 12: MCI Step1, virgin feedstock(source: own image)

Step 2 Calculate unrecoverable waste.

The next part is the end of life scenario of the product. What happens with the products at the end of their technical life? How much of this product ends up as feedstock for new products through either reuse or recycling? How much of the product is landfilled or incinerated? Recycling and down-cycling are distinctly different end of life scenarios. The down-cycled material has a lower value which can't reenter the system without changes towards the design and resulting in a lower value of the product. Down-cycling is graded on the same level as waste or incineration and is a material loss. With this in mind the following three equations can be extrapolated.

The first equation is on the amount of materials going to the landfill, incinerator or which are down-cycled. In which W_0 is the total amount of unrecoverable waste [kg]. M is the total mass of the product [kg]. The amount that is reused or recycled is derived from the fraction that will be recycled or reused. C_R is the fraction that will be recycled, C_U is the fraction that will be reused at the end of life. The summation of these two fractions can't result in a number greater than 1.

$$[2] \quad W_0 = M (1 - C_R - C_U)$$

The second is the amount of waste that is produced during the recycling process of the product to its basic components/materials, it examines the amount of materials entering the recycling process, represented by W_C in [kg]. E_R is the efficiency of the recycling process applied.

$$[3] \quad W_C = M (1 - E_R) C_R$$

The last equation is the amount of waste that is produced during the recycling of the product and turning it into feedstock again. This examines the amount of materials exiting the recycling process, represented by W_F in [kg]. E_F is the efficiency of the recycling process applied. $E_R = E_F$ in a closed loop, though this is rarely the case in reality, usually the recycling process includes the materials from a multitude of different products with different origins. Materials used don't necessarily need to end up as feedstock for the same product again, recycled materials can come from a multitude of products.

$$[4] \quad W_F = M ((1 - E_F) F_R) / E_F$$

The model expects reuse to be 100% efficient and expects it doesn't generate waste during the reimplementation into the feedstock of the original product. The efficiency for recycling is expected to be lower than 100%. The way W_C and W_F are constructed would mean when they are added together, the recycling process would count the waste cycles twice. In a completely closed loop W_C or W_F could be used because they would be equal. Because this is not the case, the total unrecoverable waste W [kg], is described with the following equation, in which it is assumed that both W_F and W_C are equally important, so the average is used.

$$[5] \quad W = W_0 (W_C + W_F)/2$$

These five equations correspond to the second half of the diagram and results in all the waste flows that can be expected.

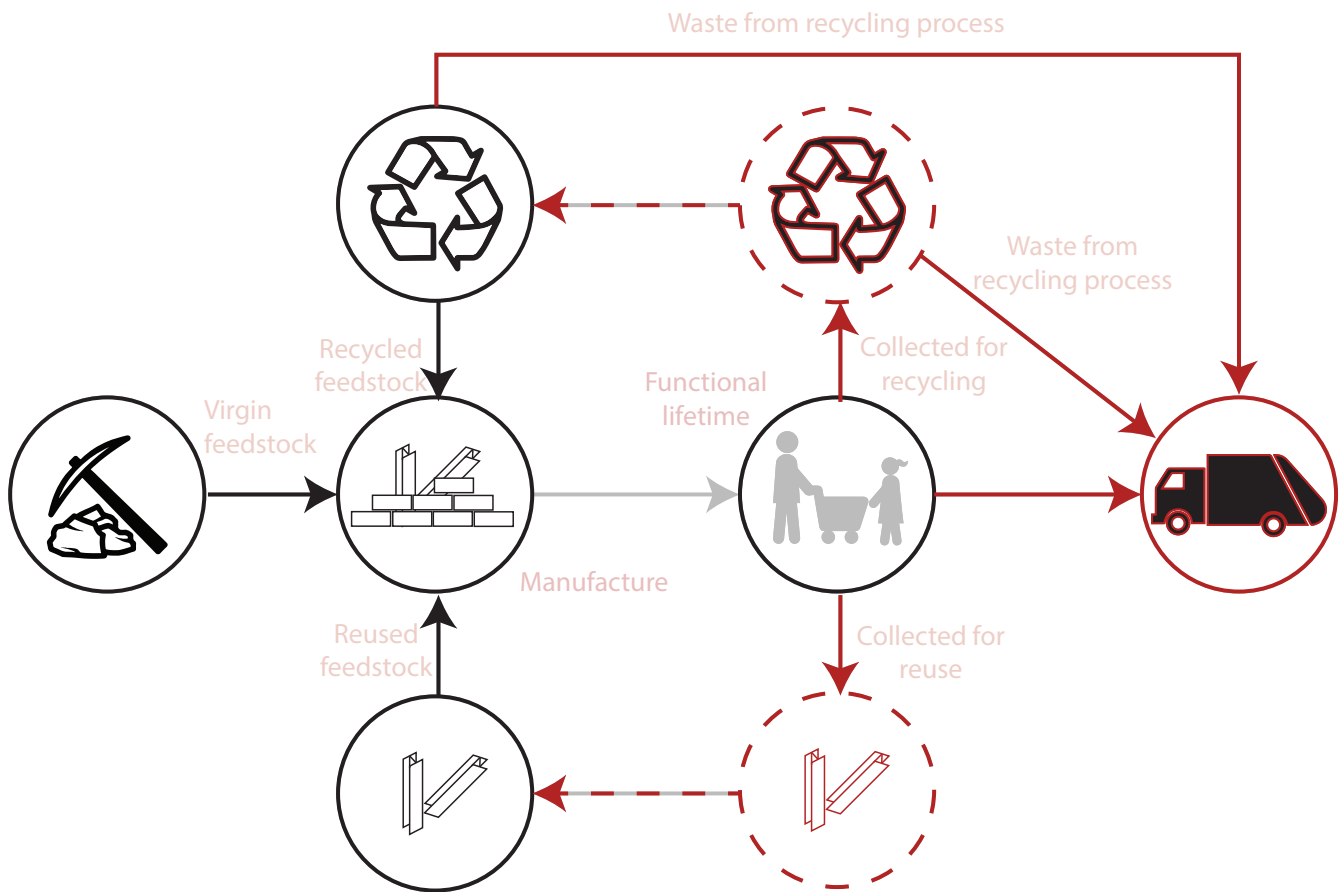


Fig. 13: MCI Step2, unrecoverable waste(source: own image)

Step 3 Calculate the LFI

The LFI is the first indicator that the model produces. It gives an insight in the material flow and what their end of life scenario is. The result is a grade between 0 and 1, 0 means a completely circular flow and 1 is a completely linear flow.

[6]
$$LFI = (V + W) / (2M + (W_F - W_C) / 2)$$

This corresponds to the outputs and inputs of the last equations.

Step 4 Calculate the UF

The resulting Utility Factor, X, is made up from two parts, the length of the products use phase and the intensity of the usage. The resulting formula looks straightforward but requires a bit of an explanation.

$$[6] \quad X = (L) / L_{av} \cdot (U) / U_{av}$$

The use length shows the comparison to the market standard. A product with a longer use life requires less resources over the same amount of time. If the use is twice as long as the market standard it needs half the resources over the same amount of time. L is the number of years the product is used compared to the number of years comparable products are used in L_{av} .

The intensity reflects on how the product is used before it reaches the end of its technical life. If a product can be used more intensely than its competitors, it allows for a more efficient use of materials.

The expected use of this equation is that either the use length or intensity is used in the calculation. If only the use life is included, this means the intensity will be assumed to be $U/U_{av} = 1$. If there is the necessity to use both factors, it is important to make sure that changes to the product aren't included twice in the calculation. Either it has an impact on the length or it has an impact on the use intensity.

This utility factor is the first time the usage is included in the calculations as highlighted in the diagram below.

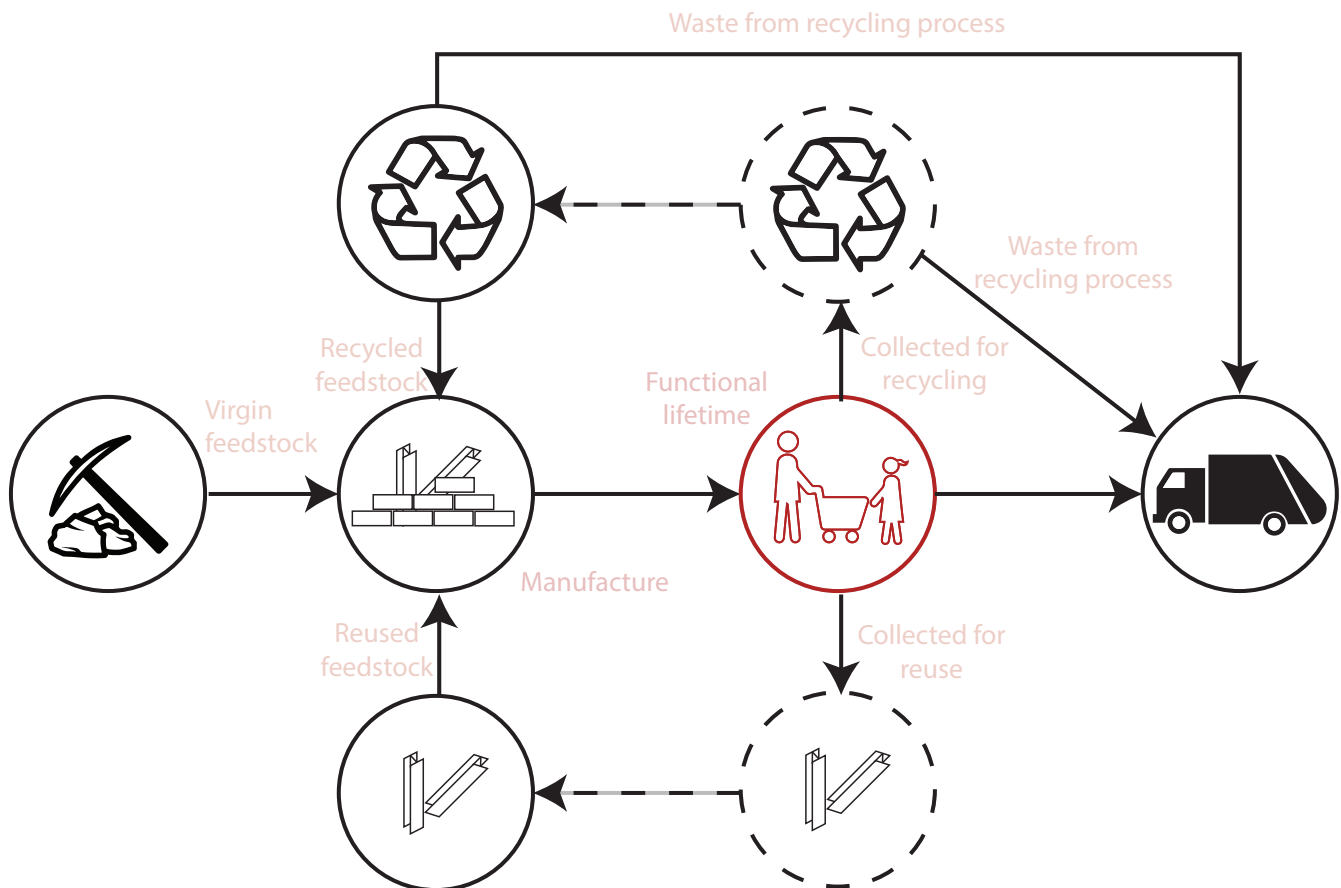


Fig. 14: MCI Step4, utility factor(source: own image)

Step 5 Calculate the MCI

The final step is the MCI itself. It combines both the LFI and UF in the final equation:

$$[7] \quad F_{(x)} = 0.9/X$$

The choice to include the function $F(X)$ is made to penalize products that have a poor use length and utilization.

$$[8] \quad MCI^*_p = 1 - LFI \cdot F_{(x)}$$

Due to the way the previous equations are assembled it is possible to get a negative MCI^*_p when the product examined is almost linear, the LFI gets close to 1, and if the UF is below average. For this reason the next equation is included to limit the MCI at 0. A product can't become more linear than fully linear.

$$[9] \quad MCI_p = \max(0, MCI^*_p)$$

With these nine equations it is possible to determine the MCI. The question, and side note of course is, of what do you want to determine the MCI? The materials, the sub-assemblies, the system or the whole product? To be able to calculate the MCI of the whole product, the knowledge about the MCI's on the material level is still needed. When multiple materials are included in a product the equations change slightly.

The following functions are a slight adaptation on the original. They don't provide the MCI for a single determined material anymore, instead they look at the combined MCI of a set, made up from multiple materials, in the following equations (x) is each individual material. The equations after the LFI stay the same.

First the amount of virgin feedstock has to be determined for the separate materials, the next step is the summation to determine the total amount of virgin feedstock. The same applies to the waste scenario's. The amount that will be reused or recycled has to be determined too. This summation leads to the total amount of unrecoverable waste for the whole product. This can again be seen in the formula for the LFI.

$$[1.1] \quad V_{(x)} = M_{(x)} (1 - F_{R(x)} - F_{U(x)})$$

$$[1.2] \quad V = \sum_x (V_{(x)})$$

$$[2.1] \quad W_{0(x)} = M_{(x)} (1 - C_{R(x)} - C_{U(x)})$$

$$[3.1] \quad W_{C(x)} = M_{(x)} (1 - E_{R(x)}) C_{R(x)}$$

$$[4.1] \quad W_{F(x)} = M_{(x)} ((1 - E_{F(x)}) F_{R(x)}) / E_{F(x)}$$

$$[5.1] \quad W = \sum_x W_{0(x)} (W_{C(x)} + W_{F(x)}) / 2$$

$$[6.1] \quad LFI = (V+W) / (2M + \sum_x (W_{F(x)} - W_{C(x)}) / 2)$$

Critical note: There are a few issues which sneak into the use of the MCI for a product. If the MCI is examined for the product as a whole instead of the individual materials the results can be skewed. When examining on a product level an improvement in the MCI doesn't directly relate to a more circular product.

As can be seen in the tables below, by only adding a new “very circular” material or layer with a high weight to the product the LFI and MCI massively improve. This way the product seems more circular while inherently nothing changes. This makes it important to choose your scope. Which materials do you include, do you include the whole system, the product or component, or just a sub assembly? These questions on scope are examined in the redesigns.

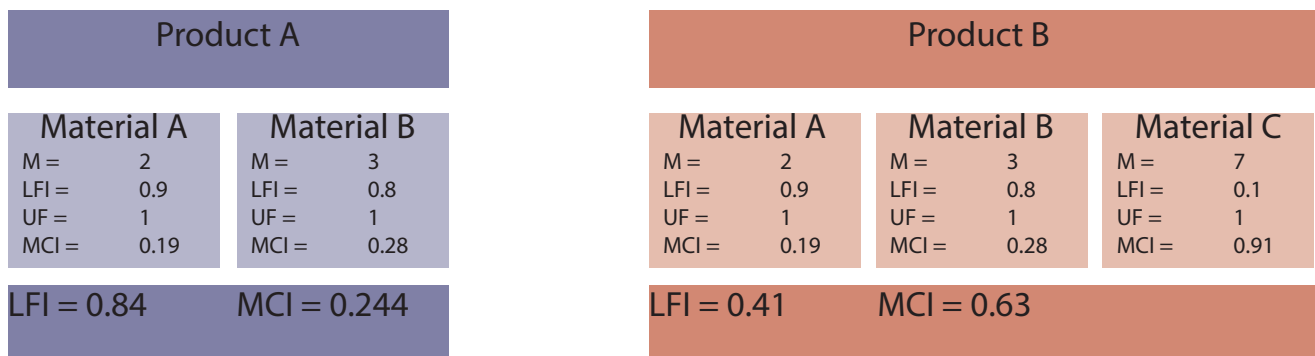


Fig. 15: MCI, vulnerability to the weighted average(source: own image)

4.3. Data source

The choice must be made on the acquisition of the material data. The data needed about the components and materials used, can be acquired through a multitude of sources. The NIBE has been used for data in the instances in this report.

The “Nederlands Instituut voor Bouwbiologie en Ecologie” (NIBE) has been around for 25 years in the Netherlands. They aim to quantify and measure the impacts on our environment of a multitude of materials used in the building industry. To collect this data, they collaborate with the “Nationale Milieudatabase”, which is comprised of data from the Dutch building industry. Besides that, they collaborate with contractors and suppliers in the building industry, through the use of LCA's. These findings are reported in their openly accessible database(NIBE, 2011). They provide data on:



- Weight of components or materials [kg].
- Technical life cycle.
- End-of-life scenarios.

4.4. Disassembly Potential

While the MCI provides insight into the sustainability of the materials, no insight is provided into the assembly. The end-of-life scenario is only partially influenced by the materials themselves. Through design you influence the end-of-life scenario, if a product is deconstructable it has a higher chance to be disassembled and reused. When a structure becomes a composite it has a higher chance to be demolished and end up as unrecoverable waste on a landfill. Basic disassembly principles have been known and used for millennia. Though constructions have become more complex many of the old principles still apply (Crowther, 1999). The difficult part is quantifying these qualitative principles. In the book by Elma Durmisevic (2010) and in her PhD thesis (2006) she uses fuzzy logic to give a possibility to measure the Disassembly Potential and compare designs. The information for the use of her model is summarized in the next chapters.

In a paper she wrote around the same time, she distinguishes four material levels (Durmisevic & Brouwer, 2006b) in a building. These are the hierarchy of the materials and their connections. The four levels present are as written in her report:

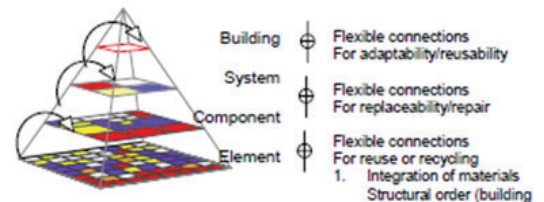


Fig. 16: material hierarchy in a building (Durmisevic, 2006a)

- Building Level represents the composition of systems which are carriers of main building functions (load-bearing, enclosure, partitioning, servicing).
- System level represents the composition of components which are carriers of system functions (bearing, finishing, insulation reflecting distributing etc.).
- Component level represents the layered or frame assembly of component functions which are allocated through the elements and materials at the lowest level of building assembly.
- Element level represents the lowest denominator that provide a sub-function.

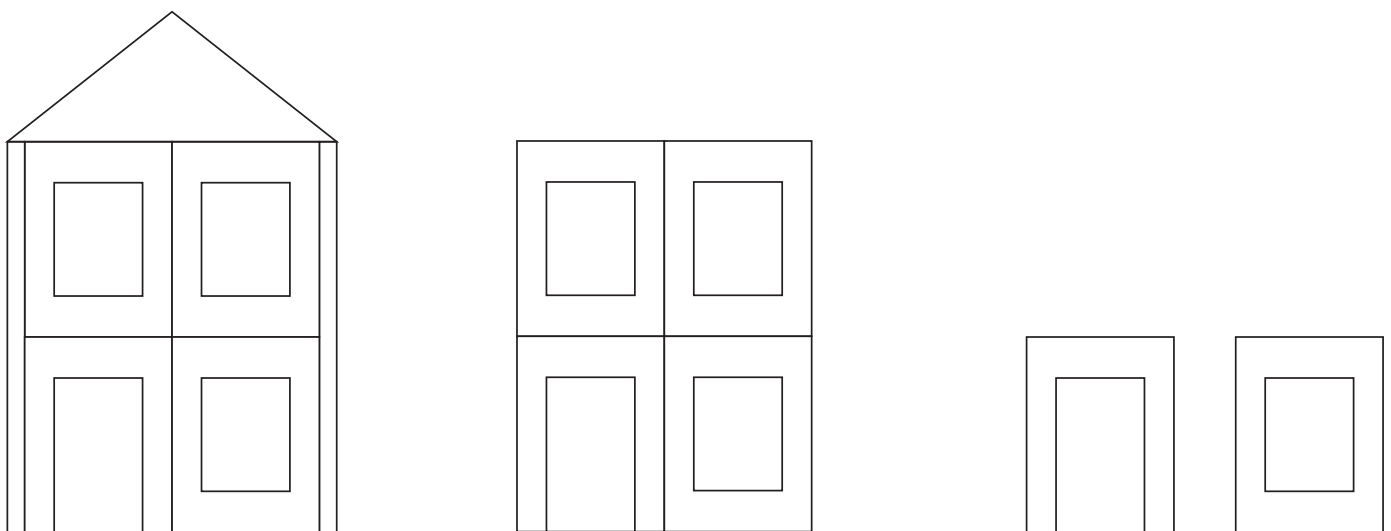


Fig. 17: Hierarchy of materials in a building, from left to right: Building, System, Component (source: own image)

These material levels used, are recurring in Durmisevic papers and book and form a large part of the understanding for the Disassembly Potential.

The model for the Disassembly Potential is build up from four output levels each level uses the previous one to provide insights in the your design on different topics. The foundation is made up through 15 inputs that can be measured in the design. If you're looking for improvements, this allows for quick deduction to pinpoint problem areas within your design. The important levels to explain are the first and fourth level. The first level provides you with the inputs and an overview of the grading criteria. The fourth level provides you with an overall score and gives you a general impression of the end-of-life scenario for your design.

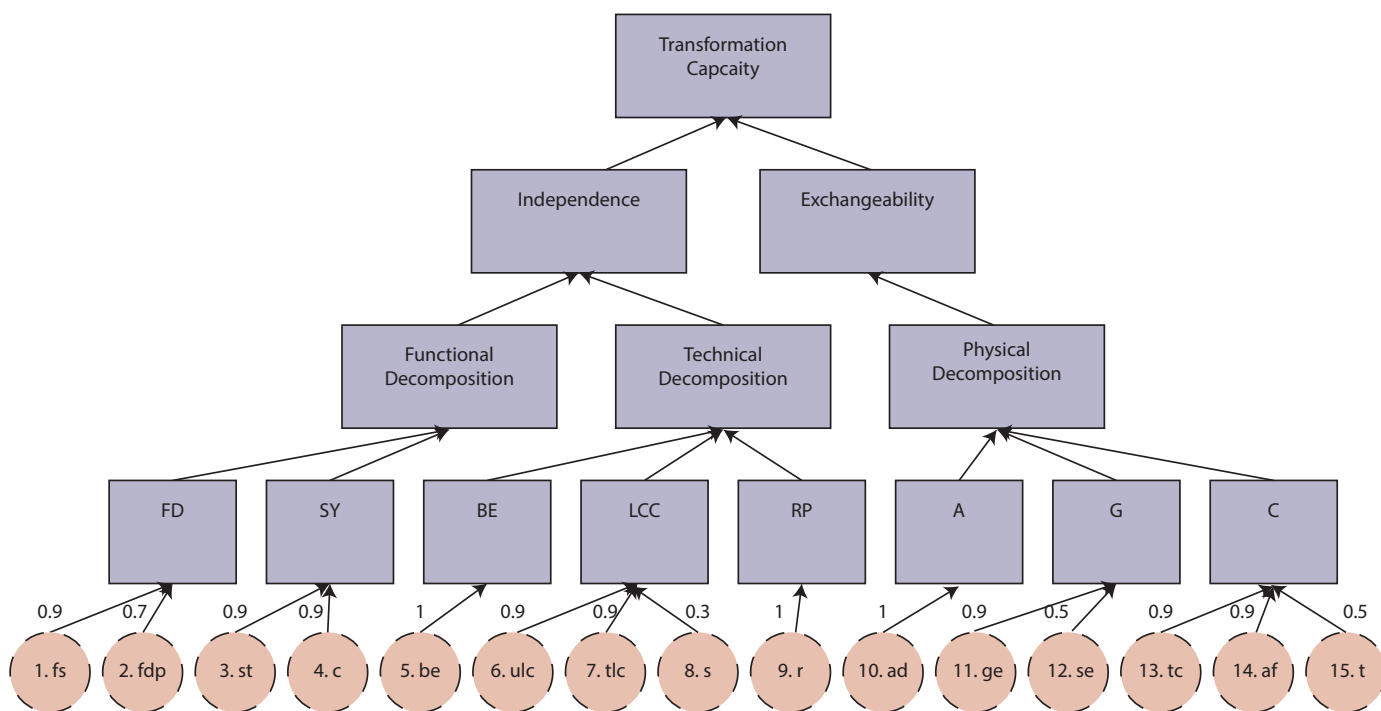


Fig. 18: four levels in the Disassembly Potential assessment (source: own image)

Level 0

This is the input layer, here all the collected data is entered, after these no extra inputs are added to the model. This is also the layer most of the assessment will be about. The four other levels provide scores and insights into the important aspects of the design.

Level 1

The first level is divided into eight aspects. Each has a large influence on the decision-making during the design process. These choices determine how and if the eventual building can be disassembled. These choices are all graded, they receive this grade which will be between 0 and 1, 0 being the worst score and with 1 providing good grounds for disassembly.

Level 2

These are the three design domains that can be distinguished. While there is still overlap between them, these are the major domains. The Functional, Technical and Physical Decomposition each cover a different area of the design aspects.

Level 3

Independence and exchangeability show the possibilities for transformation and change.

Level 4

The Transformation Capacity is the overall score, it shows the most likely end-of-life scenario for your design.

Inputs

The inputs for the model are the first assessments and guidelines. These assessments can be used in two fold. Firstly they can be used to assess a current design on it's potential to be disassembled and reused. Secondly the method can be used as guidelines for a designer to include disassembly into the design from an early stage. The assessment method uses fifteen inputs, each is an independent choice, which greatly influences the Disassembly Potential.

Functional Dependence (FD):

One of the first important decisions that has to be made during the design of a flexible structure, is how many functions a building product needs to fulfil. These choices can be divided into two criteria, Functional Separation and Functional Dependence. For a building design to have an optimal disassembly potential you want to separate functions as much as possible. This allows functions to be disassembled and upgraded when needed. There are four main functions within a building: supporting, enclosing, servicing and partitioning. You want to keep these functions completely separate. Within the functional domain, for example enclosing, a multitude of sub-functions can be expected: insulating, water tightness, air tightness, translucency, etc.

For the functions on the building level the model of Steward Brand can be consulted. He determines six layers each with its own functions (Brand, 1994). Only four layers are used in Durmisevic grading method, these layers are:

Structure:

This contains all the load bearing elements and has the longest life span, with around 30-300 years

Skin:

The skin separates inside and outside and is under constant effect from the weather, the skin usually lasts 20 years.

Services:

Services ensure the building keeps performing, they provide heating, cooling etcetera. These are all the working parts and should be updated every 7 to 15 years.

Space: provides the interior layout, divides up the room, it changes along with fashion and changes every 3 to 20 years.

All of these functions should be kept separate from each other, they all have different life cycles and maintenance rates. Durmisevic describes this in the functional separation (fs). This examines how functions are related to each other. As described in the figure below with the three functions: Bearing, Insulating, and Finishing. It distinguishes three levels:

- 1 Total separation of functions
- 0.6 Integration of functions with same life cycle into one element
- 0.1 Integration of functions with different life cycles into one element

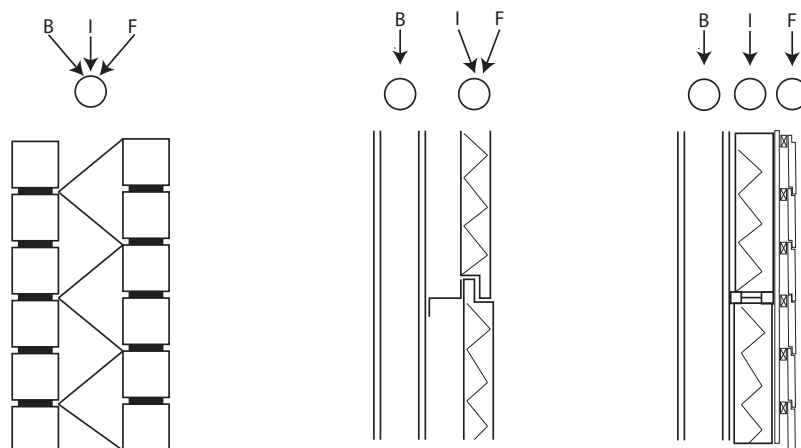


Fig. 19 Fig. 19: Functional separation. From left to right - Total integration, Integration same LC, Total Separation (source: own image)

The second grade is on the functional dependence(fdp), you want to be able to change a function when the original function is no longer in demand. This greatly influences the adaptability of a design. Five different varieties can be determined.

Functional dependence(fdp):

- 1 Modular zoning
- 0.8 Planned interpenetrating for different solutions
- 0.4 Planned interpenetrating for one solutions
- 0.2 Unplanned interpenetrating
- 0.1 Total dependence

c - construction
f - finishing
s - servicing
i - insulation

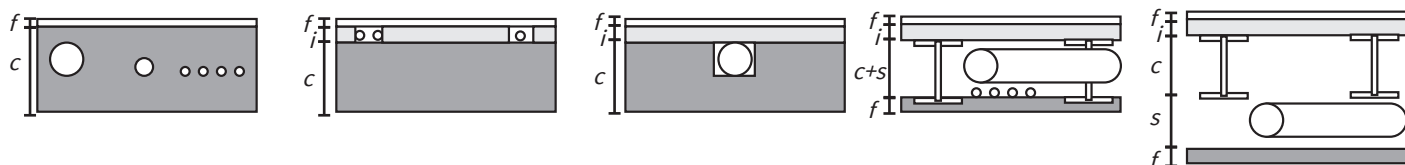


Fig. 20: Functional dependence, from left to right: Total dependence, unplanned interpenetrating, planned interpenetrating for one solution, planned interpenetrating for different solutions, modular zoning(source: own image)

Systematisation(SYS):

By examining the systematisation, a designer can be determined how parts relate to each other. These relations are important to determine in what order certain steps in the assembly take place. Building assembly can be done in one of three stages: on site, in the work place or in the factory. Knowing these steps, provide you with control on how you want to cluster your material levels. Clustering provides faster assembly procedures on site, and with it faster disassembly procedures as well. By combining materials into components you are able to minimize the amount of work that has to be done on the site. Easy assembly, with few different connections and procedures, provides extra incentive to deconstruct the building at its end-of-life. If too many are needed for disassembly, the value gained through the materials is lost in the extra labour hours spend. When this is the case, the building usually ends up demolished. Systematisation can be divided into two parts. First how do the material levels relate to each other, how many procedures have to be done on site, and secondly what was the reason for which the material clusters were made? Structure and material levels(st) is the first grade in the systematisation. This is shown with the following grades for the assessment.

Structure and material levels (st):

- 1 components
- 0.8 elements/components
- 0.6 elements
- 0.4 material/element/component
- 0.2 material/element
- 0.1 material

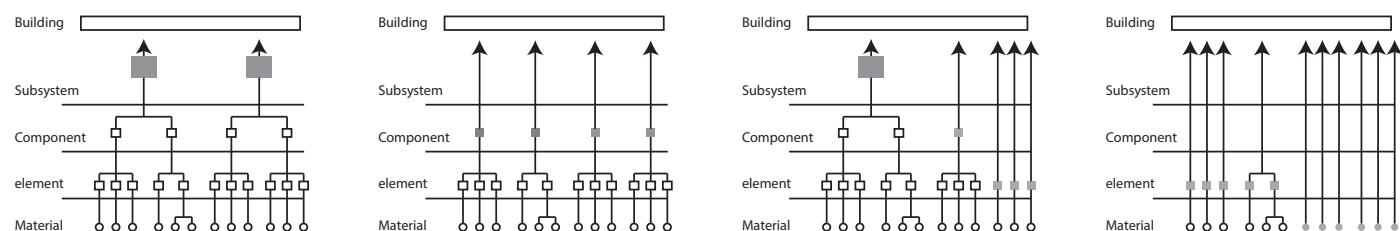


Fig. 21: Systematisation in a building, from left to right: Component, element, mat/el/component, material(Durmisevic, 2006a)

Clustering relates directly to the materials chosen for a function and how they are combined into a component or on site. The Function should determine which materials are added together in a single component, the relation between the materials should be chosen on their life cycles, this should also determine their order in the structure.

Clustering(c):

- 1 Clustering according to the functionality
- 0.6 Clustering according to material life cycle
- 0.3 Clustering for fast assembly
- 0.1 No clustering

Base Element(BE):

Each element is added to the building to fulfil a specific function or sub-function. These elements can be connected in clusters, as described in the paragraph above. These clusters need to be connected to each other too. If left undefined, the components can become dependent on each other, disassembly methods will become unclear and lead to demolition in extreme cases. To ensure components can be disassembled again, a base element needs to be added, which connects the components to the load-bearing structure, instead of connecting the components directly to each other. Four cases can be distinguished for the base element.

Base element(be):

- 1 Base element- intermediary between systems/components
- 0.6 Base element- on two levels
- 0.4 Element with two functions (base element and a building function)
- 0.1 No base element

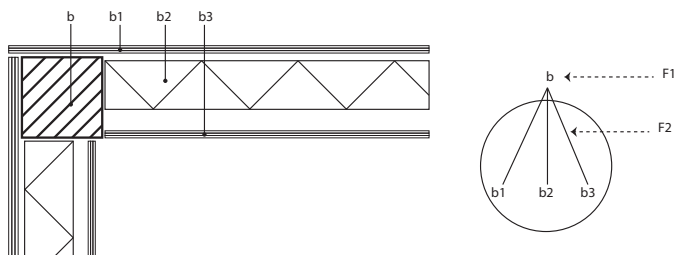


Fig. 22: Principle 1, no base element(Durmisevic, 2006a)

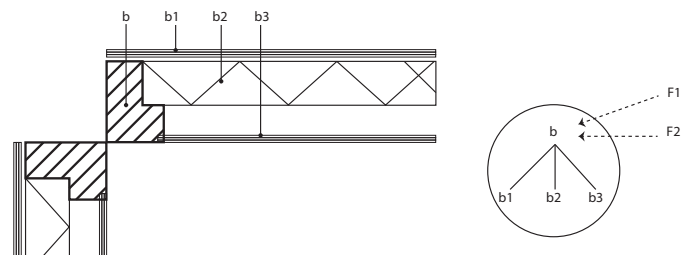


Fig. 23: Principle 2, base element with two functions (Durmisevic, 2006a)

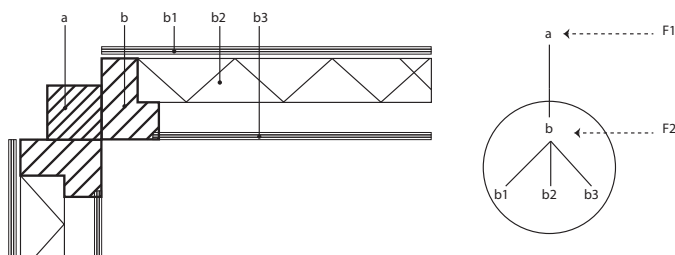


Fig. 24: Principle 3, Base element on two levels(Durmisevic, 2006a)

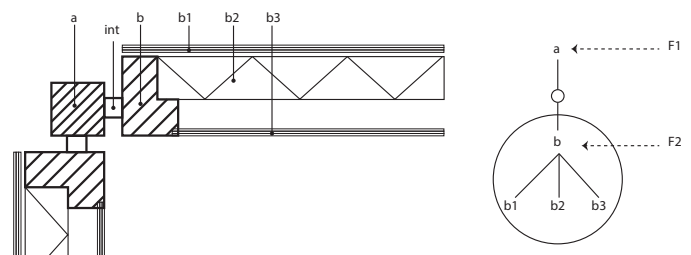


Fig. 25: Principle 4, base element with intermediary(Durmisevic, 2006a)

In the first principle, the construction is almost completely assembled on site. In this situation the façade elements (F2) have a direct relation with the load bearing elements (F1). In the second principle the two functions are clustered into a single component. While still being fully dependant on each other, the components can now be assembled off site, making assembly easier. When you want to change a façade panel, it'll have consequences on the stability of the structure as a whole. In the third principle, the functions of load-bearing and façade are separated by the addition of a load-bearing element 'a'. This allows the façade panels to be assembled separately without being dependant on each other. Due to the close assembly, replacing a panel is still difficult. In the fourth principle, an intermediary is added. By not connecting the façade panels directly to the load-bearing structure you are able to replace each element independently without compromising any other element.

Life Cycle Coordination(LCC):

Buildings have the interesting aspect that the materials incorporated into their design have a wide variety of technical life spans. Some materials last 5 years others last over 100 years(SBR, 2011). These life spans are also highly dependant on maintenance and cleaning throughout their functional life span. Many materials can last for far longer than the one prescribed by the SBR. Two life spans can be determined for building materials, the 'functional life span' and the 'technical life span'(Blok, Herwijnen, Kozlowski, & Wolinski, 2015). The functional life span is the period for which a structure can still meet the demands of its users. The technical life span refers to the time it takes before a product starts to perform below its technical specifications for its intended purpose. The Life Cycle Coordination compares the two types of life span. As a designer you want materials with a long technical life span as your load-bearing structure, these materials need the least amount of maintenance, as they are expensive or almost impossible to replace. When those materials need to be replaced all other functions in the building will have already become obsolete a multitude of times. The use life cycle/ coordination examines the materials/element/component Technical service life (1) to their functional life (2). The technical life cycle examines the connection between two materials that exist on a different level, material (a) to material (b), you don't want a long lasting material to rely on a short lasting one. When the short lasting material needs replacing, you directly need to replace all long lasting materials or components as well.

Use life-cycle/ coordination(ulc):

- 1 Long(1)/long(2) or short(1)/short(2)
- 0.8 Long(1)/short(2)
- 0.5 Medium(1)/long(2)
- 0.3 Short(1)/medium(2)
- 0.1 Short(1)/long(2)

Technical life-cycle/ coordination(tlc):

- 1 Long(a)/long(b) or short(a)/short(b)
- 0.8 Long(a)/short(b)
- 0.5 Medium(a)/long(a)
- 0.3 Short(a)/medium(b)
- 0.1 Short(a)/long(b)

The last life-cycle coordination which is important to examine is the use life cycle related to its size. Small elements can have shorter life cycles. When they are light weight and are easy to handle, they can be replaced without much hassle.

Use life-cycle/size(s)

- 1 Big (small) element / long L.C.
- 1 Small element / short L.C. or medium component / short L.C.
- 1 Big component / long L. C.
- 0.4 Big component / short L. C.
- 0.2 Material / long L.C.
- 0.1 Big element / short L.C.

Relational Pattern(RP):

The relational pattern shows how different functions depend on one another. In more traditional architecture, all functions would depend on each other and become one monolithic diagram, where no changes could be made without interfering with another function. As described in the BE section, sub-systems should only have relations with the load bearing system. In that case, elements can easily be replaced when necessary. Two types of relations can be determined, relations within a functional group and relations between functional groups. The first one, within a functional group, are defined as vertical relations. The second type of relation is the horizontal relation. These types of relations must be avoided where possible as they complicate replaceability.

Relational patterns (r):

- 1 Vertical
- 0.6 Horizontal in lower zone
- 0.4 Horizontal between upper and lower zone
- 0.1 Horizontal in upper zone

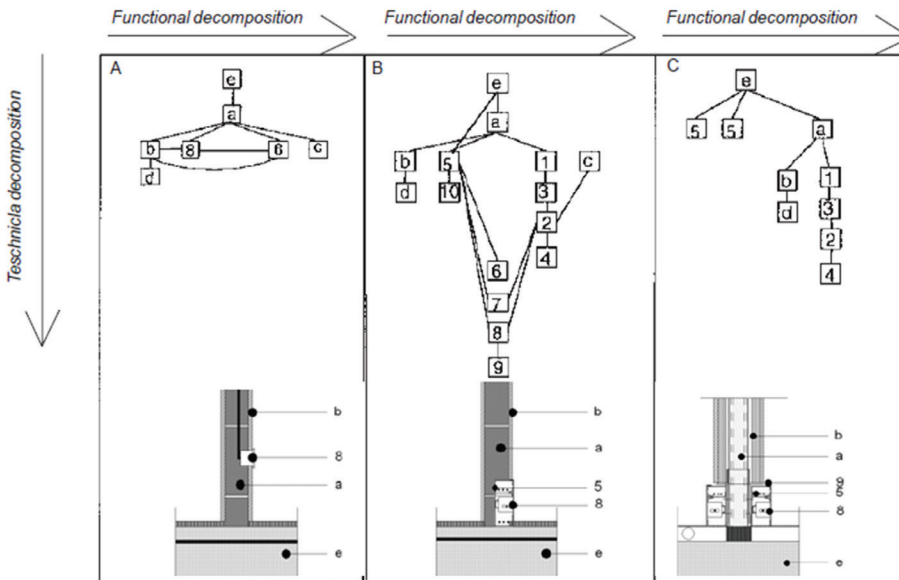


Fig. 26: Relational patterns in a wall system. Horizontal relations are common in static configurations and vertical relations are common in dynamic configurations. From left to right: Static, partially dynamic and dynamic wall systems. (Durmisevic, 2006a)

Assembly(A):

The method of assembly, can make or break the independence of functions. They determine if a building can be disassembled or if parts can be replaced during its life cycle. During the assembly, you can see what should happen in reverse at the buildings end-of-life. There is one factor to be measured during the assembly, the assembly direction. Assembly direction determines your replaceability and the speed of both your assembly and disassembly

Assembly direction(ad):

- 1 Parallel
- 0.6 Stuck assembly
- 0.4 Base element in stuck assembly
- 0.1 Sequential assembly

Geometry(G):

The geometry of the product determines the assembly sequence, ergo it also directly influences the disassembly of your design. There are six distinct variations that can be made in the geometry edge. In the optimal circumstances components can be placed and replaced without interfering with components surrounding it, in the worst case demolition is your only option because components are stuck. The second criteria on which it is graded, is the standardisation of the geometry. This determines if the geometry is made on site or prefabricated.

Geometry of product edge (ge):

- 1 Open linear
- 0.8 Symmetrical overlapping
- 0.7 Overlapping on one side
- 0.4 Unsymmetrical overlapping
- 0.2 Insert on one side
- 0.1 Insert on two sides

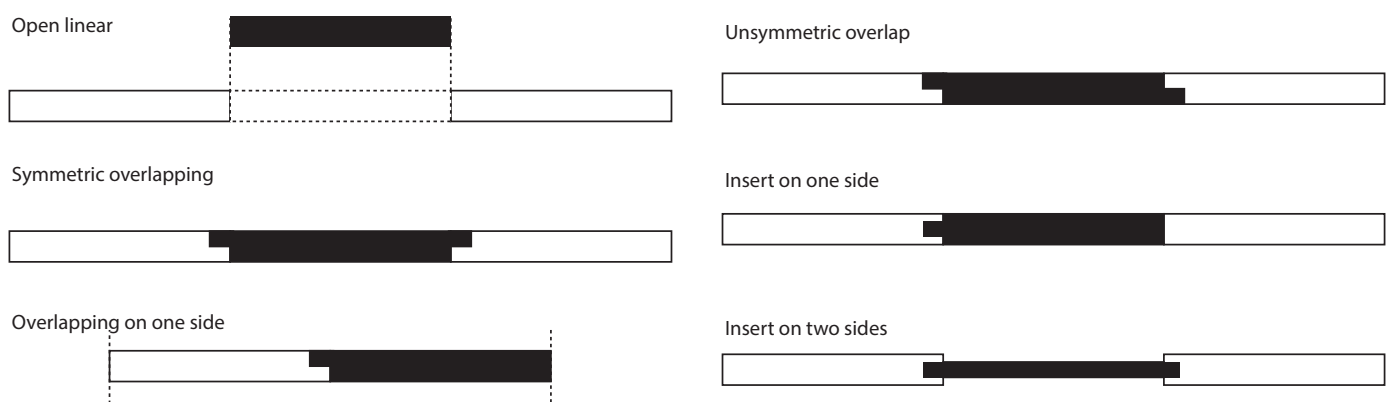


Fig. 27: Geometry of the components edge (source: own image)

Standardisation of product edge (se):

- 1 Pre-made geometry
- 0.5 Half standardised geometry
- 0.1 Geometry made on site

Connections(C):

The last aspect analysed in the Disassembly Potential are the connections. These determine the amount of freedom you have between your components. Three domains in connections can be determined, direct (integral), indirect (accessory), and filled. Each has a multitude of applications in between. The different kinds of connections are described by figure 28. Direct or chemical connections are irreversible connections, these can't be reversed without destroying a layer. Paint or poured concrete are two examples. Direct connections are connections for which the shape of the material itself determines the connection. Indirect chemical connections are, for example, different kinds of masonry. Direct connections with an fixing device are the bolted or screwed connections. The indirect connection via an third component can be curtain walls, the plates are held in place by a clamping profile. Indirect via additional fixing device is used often in wood structures, where the wooden load-bearing beams are connected to each other through a steel node.

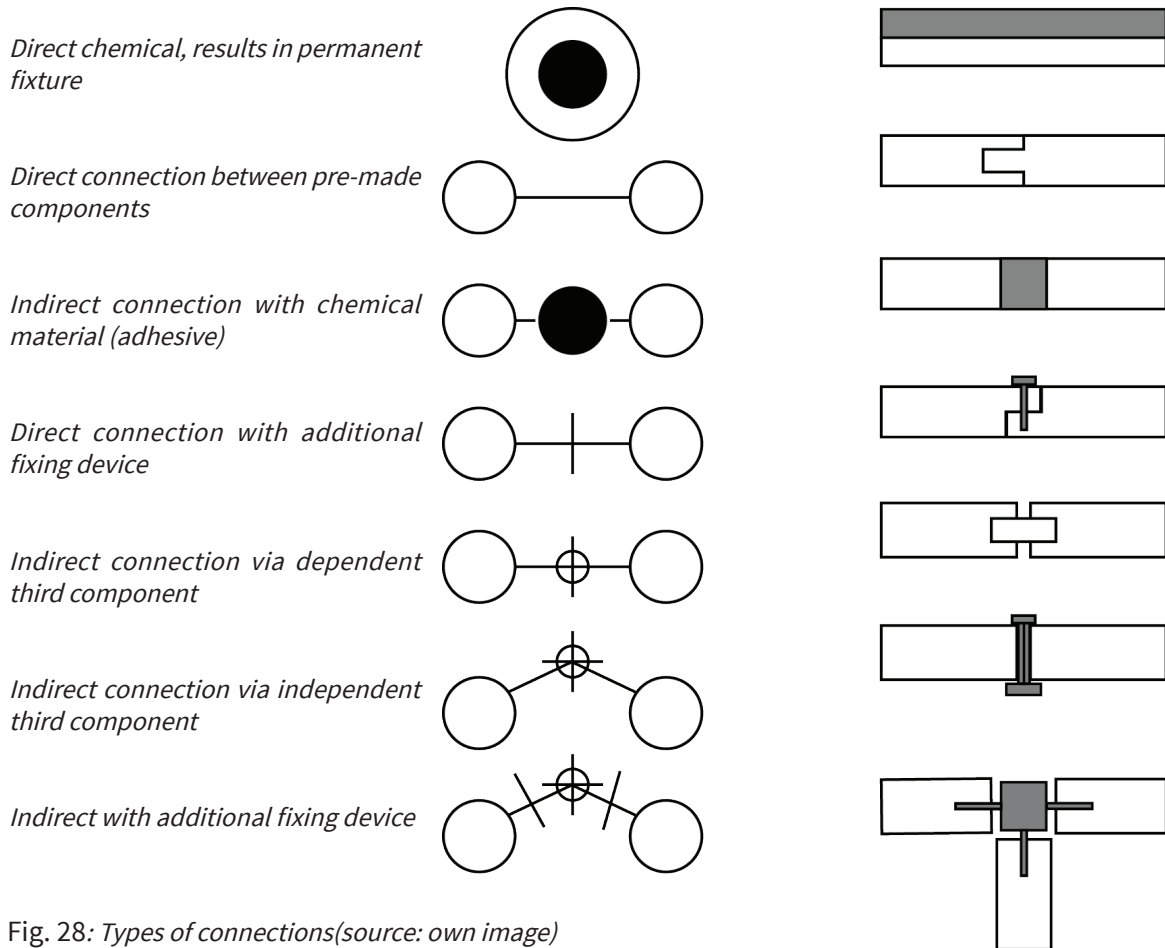


Fig. 28: Types of connections(source: own image)

These are the connection types(tc)

- 1 Accessory external connection
- 0.8 Direct connection with additional fixing devices
- 0.6 Direct integral connection with inserts
- 0.5 Direct integral connection
- 0.4 Accessory internal connection
- 0.2 Filled soft chemical connection
- 0.1 Filled hard chemical connection
- 0.1 direct chemical connection

The next step is to determine how accessible these connections are. Are you able to disassemble one without having to destroy another connection or component? This is the accessibility to fixings and intermediary (af):

- 1 Accessible
- 0.8 Accessible with additional operation which causes no damage
- 0.6 Accessible with additional operation which causes repairable damage
- 0.4 Accessible with additional operation which causes damage
- 0.1 Not accessible – total damage of bought elements

Along with the accessibility manoeuvrability is also an important aspect. How stuck is the component in the design? If there is room for movement the part can be extracted without fearing for extra damage. This is the second to last grading, the tolerance (t):

- 1 High tolerance
- 0.5 Minimum tolerance
- 0.1 No tolerance

The model for the Disassembly Potential

The result of all these inputs is the eventual Transformation Capacity.

The transformation capacity is the final grade and step in the model. It provides insight in the disassembly potential of a building structure and it provides insight into the end-of-life of a building. The grade provided by the model ranges between 0 and 1. This can be divided into one of three end-of-life scenario's for the structure.

- $0 < TC < 0.33$, these building materials will end up in the standard construction waste stream. 70-100% of the buildings waste will either be down-cycled or end up on the landfill.
- $0.33 < TC < 0.66$, these buildings can be partially disassembled, 30-70% of the materials will end up down-cycled, landfilled or incinerated.
- $0.66 < TC < 1$, this building can be almost completely disassembled. 0-30% of the waste will end up down-cycled, landfilled or incinerated.

This score is provided by an excel model, each of the aspects ascribed in the chapter above has a different impact on the disassembly potential. Not all are graded equal, for this weights are attributed to the grades given. The resulting model provides insight into the areas which need a different design. The resulting model looks like the model shown. The weights for each of the inputs is shown in the table below. All inputs can be acquired by using the form in Appendix B, this contains all grading criteria and scores.

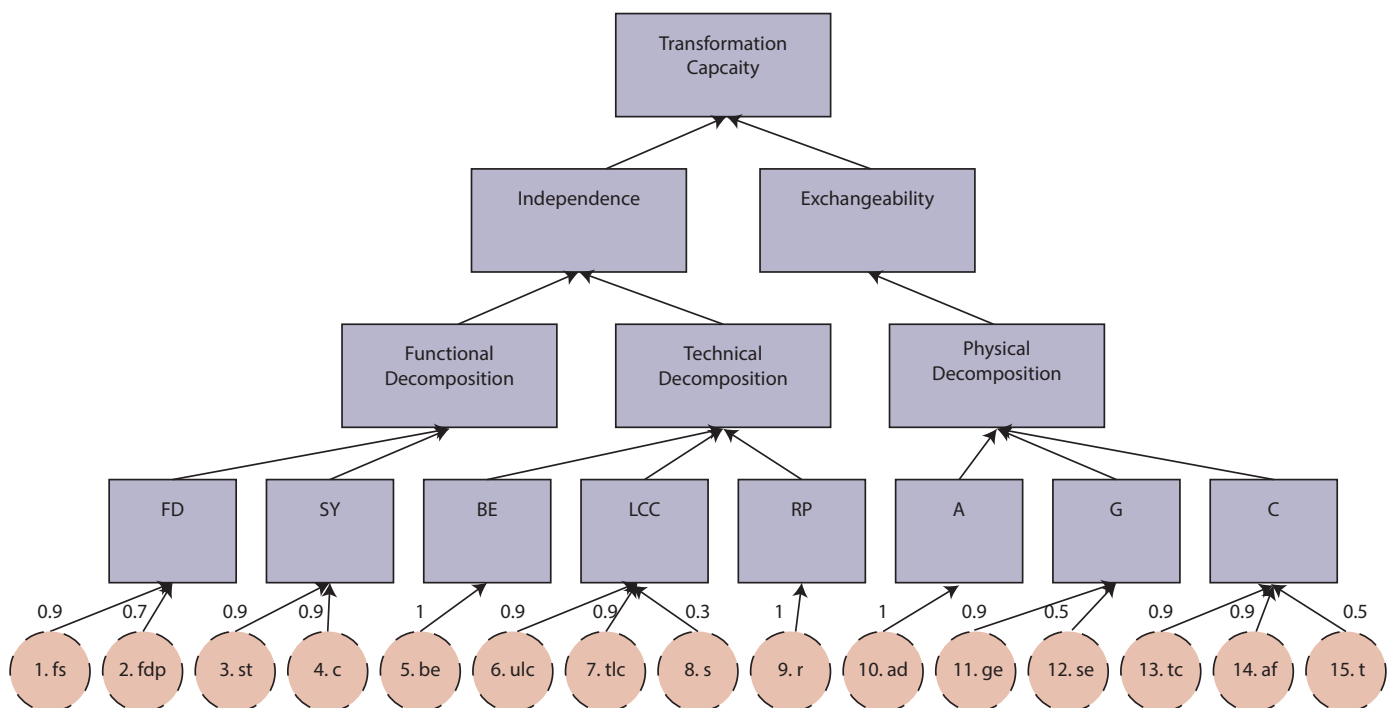


Fig. 29: four levels in the Disassembly Potential assessment (source: own image)

node	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0.9	0.7	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0.9	0.9	0	0	0	0	0	0	0	0	0	0	0	0	0
3	1		0	0	0	0	0	0	0	0	0	0	0	0	0
4	0.9	0.9	0.3	0	0	0	0	0	0	0	0	0	0	0	0
5	1		0	0	0	0	0	0	0	0	0	0	0	0	0
6	0.9	0.7	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0.9	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0.9	0.9	0.5	0	0	0	0	0	0	0	0	0	0	0	0
node	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
9	0.9	0.9	0	0.4	0.3	0	0	0.3	0	0	0	0	0	0	0
10	0	0.4	0.9	0	0.9	0.7	0	0.3	0	0	0	0	0	0	0
11	0	0	0	0.9	0	0.7	0.7	0.9	0.2	0.2	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0.9	0.9	0	0	0	0	0
13	0	0	0.4	0	0.2	0	0	0	0	0	0.9	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0.9	0.9	0	0

Ideal node	1	2	3	4	FD	Outputs	node
1	1	1	0	0	FD	0.9125	1
2	1	1	0	0	SYS	0.9	2
3	1	0	0	0	BE	1	3
4	1	1	1	0	LCC	1	4
5	1	0	0	0	RP	0.6	5
6	1	1	0	0	A	0.6	6
7	1	1	0	0	G	1	7
8	1	1	1	1	C	0.687	8

Actual node	1	2	3	4	Material levels	Outputs	node
1	1	0.8	0	0	Material levels	0.8633	9
2	0.8	1	0	0	Hierarchie	0.7582	10
3	1	0	0	0	interfaces	0.8229	11
4	1	1	1	0	Independence	0.8107	12
5	0.6	0	0	0	Exchangeability	0.8404	13
6	0.6	0.6	0	0	TC	0.8256	14
7	1	1	0	0			
8	0.6	0.6	1	0			

Fig. 30: Disassembly potential excel model (source: own image)

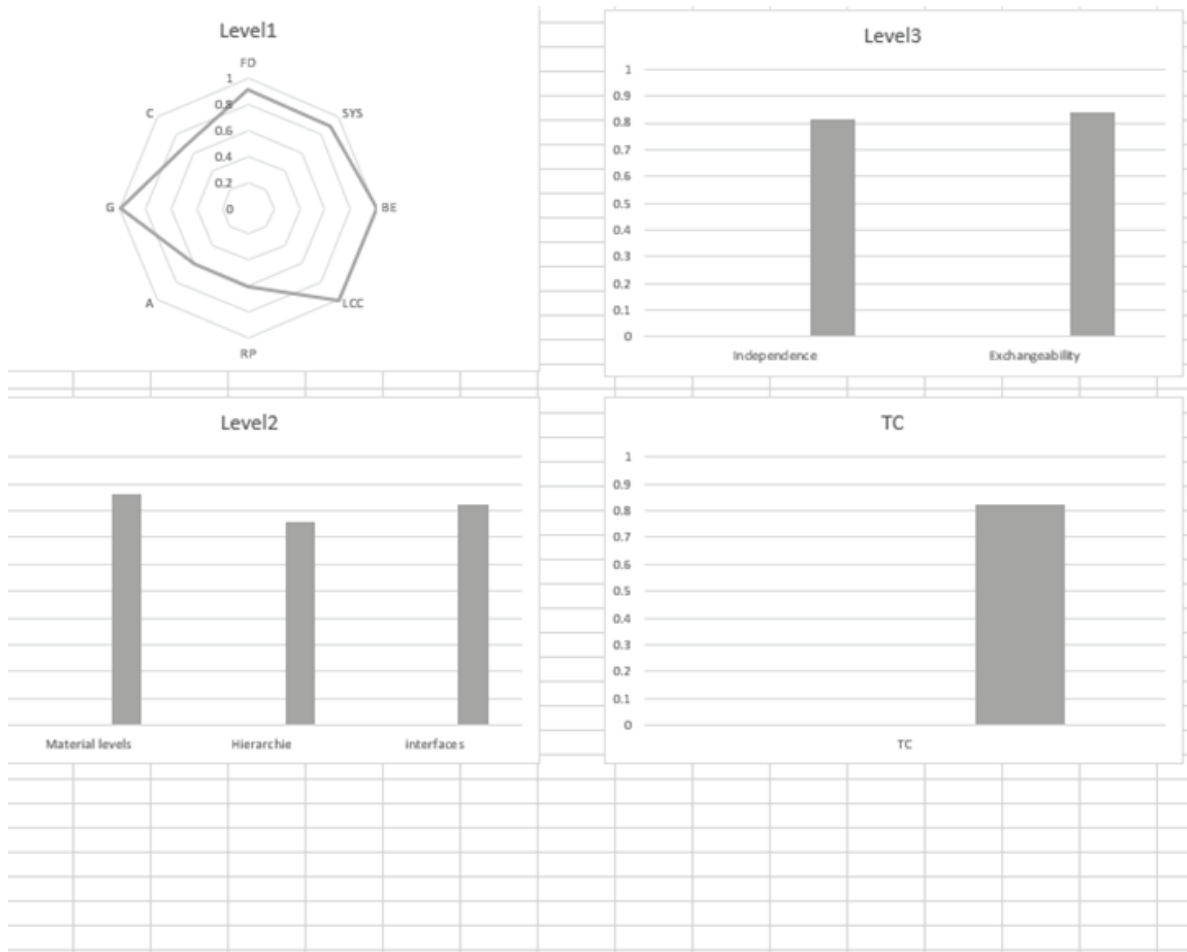


Fig. 31: Disassembly Potential levels in graphs(source: own image)

4.5. Conclusion

Out of the five methods analysed by Quirine Henry(2018) only three could be used to assess and compare circularity in designs, the LCA, MCI and DP. These three assessment methods on their own aren't enough to cover all of the requirements for assessing circularity. Out of these three methods the MCI and DP are used to further assess the circularity of the designs in the report.

This still leaves an gap in our knowledge, as a full circular assessment method should provide information on the five key requirements of the Circular Economy:

- Reducing the input and use of natural resources.
- Reducing emission levels.
- Reducing valuable material losses.
- Increasing share of renewable and recyclable resources.
- Increasing the value durability of products.

The method that covers most of these assessment qualities is the MCI, except for the reduction in emission levels. The inputs for the MCI currently don't allow for the implementation of the biological cycle either. The Disassembly Potential does influence the emission levels and a high Disassembly Potential seems to correlate with lower emissions. Though these two assessment methods won't provide an insight in how much your emissions levels have changed. This lack of information can make further choices on a material or supplier difficult.

The Material Circularity Indicator is a tool, which is easy to apply to a product case. The tool doesn't require in depth knowledge on the material cycle, most data can be directly obtained from the supplier and their existing supply chains. This ease of use results in an easily influenced and misused formula. The scale on which the formula is applied, material, product or a whole building, greatly determines how reliable and comparable the information is. The equations result in a weighted average to calculate a combined MCI. If weight is chosen for this average, low weight materials will have a smaller effect on the MCI. The MCI will completely be determined by the heavier materials. Carbon footprint, shadow costs, or price in general can all be used to determine an weighted average, each will provide a different score for the combined circularity.

While the MCI gives a view on the circularity of the materials, the Disassembly Potential examines the connections and relationship between materials. It examines how the materials are going to be combined in components or on-site, and fulfil their function in the built environment. The Disassembly Potential is less reliant on standardised inputs, this makes it more subjective and vulnerable to biases. Two independent analysts can give a structure two completely different scores due to the fuzzy logic. This makes the Disassembly Potential less reliable just on its own, it's a better tool for designing for disassembly than for assessing disassembly.

These two assessment methods give an impression on the current Circularity of the design. The two assessment methods give a decent prediction on the maintenance, transformability and end-of-life scenario of your design. No real comments can be made on the Circularity of renewable sources, as the methods completely ignore this side of the Circular Economy. The assessment methods also don't provide insight into the distinctions between materials which are deemed to be circular as the emission and environmental impact are completely ignored.

5 WHAT ARE THE CIRCULAR BOTTLENECKS IN LIDL'S CURRENT SPECIFICATION?

The Lidl's Specification is a 143 page document. This document contains, as can be found in the previous chapter, information on the materials used and the connections and the suppliers. In this aspect it's an interesting document to assess the current circularity of the Lidl's building management strategies. The Specification is divided into the type of a material or the system it belongs to, for example. These divide the Specification into 29 chapters, each covering a major system or type of material. These divisions are the main code for the materials, for example steelworks fall under code 25. These codes are further divided into sub-codes. These sub-codes are the multiple applications, calculations or side notes for the materials. To address steelworks again, this contains information about the load-bearing structure (code 25.02), the calculations (code 25.03) and the steel roof (code 25.04). This Specification is included in the appendix, the codes used in this chapter reference directly to the ones used in the Specification itself.

5.1. Framing the analysis

The order of the chapters in the Specification will be changed slightly within this analysis. The order on which the chapters will be assessed, is the same order that they fit within the shearing layer model of Steward Brand. The analysis starts with the layer with the longest life cycle and work back to the short life cycles. Some of the codes within the Specification fit into multiple layers, they'll be discussed on their performance in both of them. The layers in which they will be divided are, as shown in figure 32 (Brand, 1994).

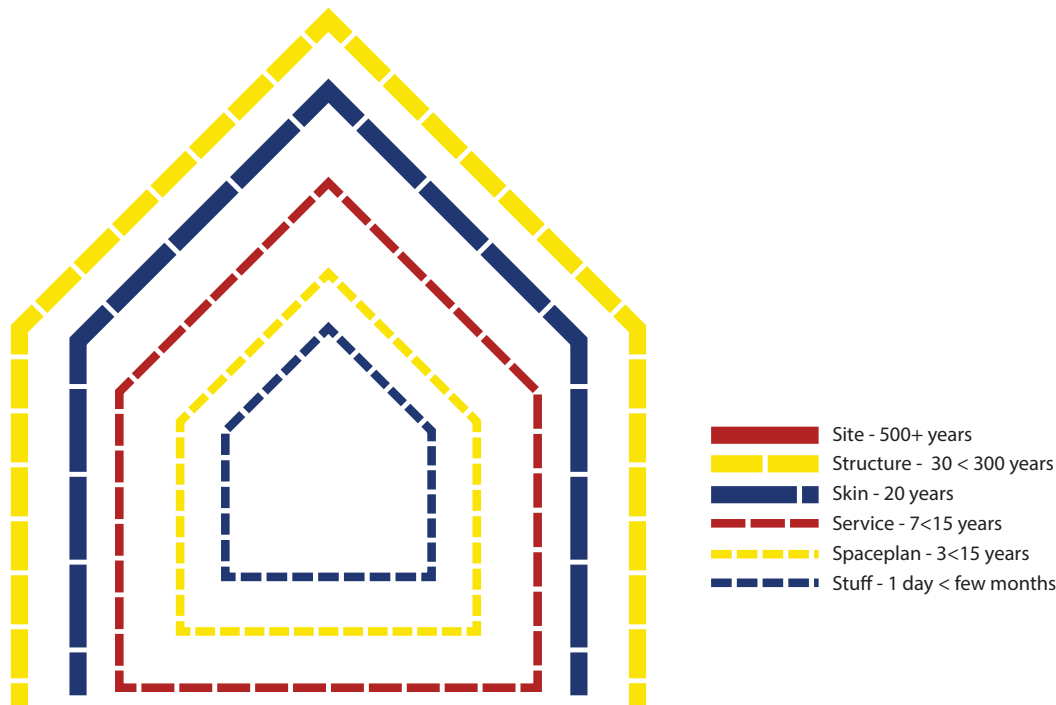


Fig. 32: Shearing layers of change based on Steward Brands model (source: own image)

These layers show how long a certain section of the Specification will be around for, this life expectancy will be used as the expected functional life in the products used within the Lidl's Specification. Once the codes are divided into their respective layers, most of the codes will be assessed on their circularity. The Stuff layer from the model of Steward Brand will be excluded from the Specification analysis. This layer is not represented in the Architectural Specification. The analysis will show which of the building systems will be redesigned in the next chapter. The Specification will be assessed on: the three principles of the Circular Economy described in chapter 2, the MCI of the materials, and the Disassembly Potential. It is difficult to determine what the actual functional life span of a product will be, as the market for the Lidl is very volatile. The Lidl's supermarkets are under constant change because they get renovated every 8 years (Lidl, personal communication, 20-3-2018). This makes it difficult for the products to determine an LFI as it is not clear how much gets renovated. Though for the DP no in depth score will be given for the individual codes, the assembly principles applied in the Specification lack the context of the surrounding materials and components. An assessment will be given for these codes and result in one of three grades:

- **Sufficient:** With a few minor changes it can a circular product. The products produces no waste at its end-of-life scenario, is fully in the biological cycle (harvested and grown sustainably) or has the potential to have a fully recycled feedstock. The product could be easily reused with the right material management.
- **Partially sufficient:** Changes have to be made to make the part circular. Either the material has potential to be completely circular but not with the current assembly method, or the overall assembly method enables reuse and recycling but the material itself isn't circular
- **Insufficient:** The code requires a complete redesign to be able to become circular. Neither the material or the assembly method can become circular.

One of the insufficient parts will be chosen to examine how it can be redesigned into a circular one, this one will also be used to show which additions and changes have to be made to the Specification before being able to be applied.

While most of the Specification is ordered in a way that fits directly into the Steward Brand diagram a few codes contain information for multiple layers. Those layers will be discussed the first time they appear in the ranking, but for clarity they are put in both cases.

Within the analysis some layers will be missing a full analysis, the Material Circularity Indicators can be found in appendix D.

SITE	SERVICES
10 - Stut- en sloopwerken	51 - Binnenriolering
12 - Grondwerk	52 - Waterinstallaties
13 - Bemaling	53 - Sanitair
14 - Buitenriolering en drainage	54 - Brandbestrijdingsinstallaties
STRUCTURE	SPACEPLAN
20 - Funderinspalen en damwanden	41 - Tegelwerken
21 - Betonwerken	42 - Dekvloeren en vloersystemen
22 - Metselwerken	43 - Metaal- en kunststofwerken
<u>24 - Ruwbouwtimmerwerk</u>	44 - Plafond- en wandsystemen
<u>25 - Metalen draagconstructies</u>	45 - Afbouwtimmerwerk
SKIN	46 - Schilderwerk
30 - Kozijnen ramen en deuren	48 - Vloerbedekking
31 - Systeembekleding	<u>22 - Metselwerken</u>
33 - Dakbedekking	<u>24 - Ruwbouwtimmerwerk</u>
34 - Beglazing	
35 - Natuur- en kunststeen	
37 - Isolatie	
38 - Gevelschermen	
40 - Stukadoorwerken	
<u>25 - Metalen draagconstructies</u>	

Fig. 33: Specification divided among the Six S model (source: own image)

5.2. Site

The first layer within the diagram is the site layer. The site contains the details about the surrounding of the design. The geographical location, the geological properties, urban context and infrastructure. Four codes can be examined to fall within this layer.

10 Stut- en sloopwerken

The first step before being able to build the new structure is to remove pre-existing structures. This is described in code, '10 Stut- en sloopwerken'. Of course it's questionable when the responsibilities of the client start to enforce the circular mind set. The decisions about how the pre-existing structures are demolished or what happens to the demolition waste is left to the contractor, this is shown in code 10.01.06. The Lidl tries to maintain an overview about what happens with the existing greenery on the construction site. As 10.01.07 shows, no interventions to the greenery should be made without their consent. Existing sewage infrastructure should also be maintained. If parts are on site that must not be demolished they will be described under heading 10.03. For the reuse of parts they can be described under heading 10.04. All parts not described within either of these codes are of no value to the Lidl, they are for the contractor.

12 Grondwerk

The above part shows the setup for a circular approach, where there is potential for reuse materials,

14 Buitenriolering en drainage

The more interesting part of the site besides demolition, is the '14 Buitenriolering en drainage'. It's the first addition that is made to the site. Three types of drainage are described within the Specification. The first is the outside sewage system (14.02). The second is the concrete drainage tub(14.03). The third part is the rainwater drainage system(14.04).

infrastructure and pre-existing construction the possibility is added. Reuse of building materials and pre-existing structure will always score higher than the use of virgin building materials and reduce the demolition waste from the site. '12 Grondwerk' doesn't directly intervene with the waste on site, of course the soil needs to be displaced but there isn't much of a loss in value. Contaminated soil can be cleaned professionally off-site.

The first part, the outside sewage is made from PVC elements. PVC or as its chemical formula Polyvinyl Chloride, These are connected to each other through either adhesives or mechanically(14.01.04). If assembled mechanically it should be possible to completely recycle the piping at its end of life. The end of life scenarios of the PVC show that 10% still ends up on the landfill and 20% incinerated, even though it can be fully recycled(NIBE, 2018g). There is a catch with this full recyclability though. Two types of recycling can be used, mechanical recycling or chemical recycling. In mechanical recycling the PVC is ground to granulate, each time it's ground down it loses a bit of its strengths. In the chemical recycling process the thermoplastics are (Stuurgroep PVC, 2018) Only clean PVC can be recycled, PVC contaminated by the use of adhesives can't be recycled. These parts they are incinerated at their end of life. The PVC piping has a life-cycle of 50 years.

Material Circularity Indicator

With this data the calculation can be made for the Material Circularity Indicator. The inputs are described in the previous paragraph, the only input missing is the weight, according to the NIBE database the weight for the PVC would be 10.8 kg/m. It provides the following results:

LFI = 0.648 UF = 1 MCI = 0.4168

Disassembly Potential

For the Disassembly Potential it completely depends on the type of connection used. In the best case the connections are made mechanically.

The second part is the concrete rainwater drainage(14.03). It's a polymer concrete system, applied under the loading docks. This part will be skipped for now, concrete will addressed as a whole when code 21 is discussed.

These three codes describe the labour that has to be applied to the site in general. It's difficult to determine how circular these works are due to them depending on what's already on the location, how much of that will be reused and how much will be demolished. The additions that have to be made don't score to badly, especially on the Disassembly potential. If adhesives are avoided the pipes could be reused or recycled.

Disassembly Potential

The Disassembly Potential for the steel piping used is quite high. The pipes are connected indirectly to the wall through the use of clamps, the water tightness is ensured by the overlap in the piping. This overlap allows water to flow down without requiring adhesives to prevent against leaking. The clamping system enables the pipes to be connected and reconnected independently of each other. The rain water drainage is a separate layer from the rest of the structure, it can be sized according to the demanded functionality.

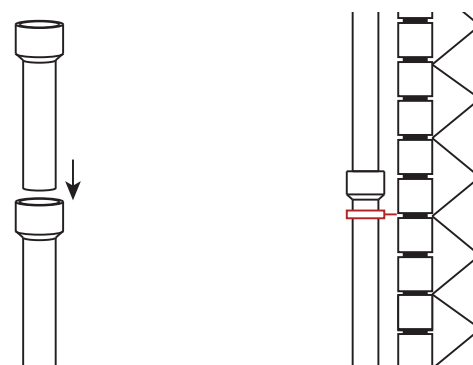


Fig. 34: Rain pipe connections (source: own image)

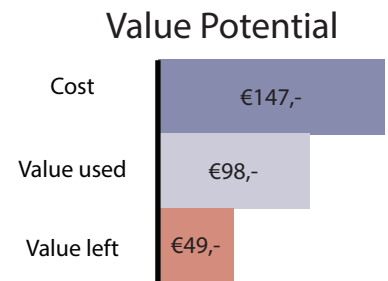
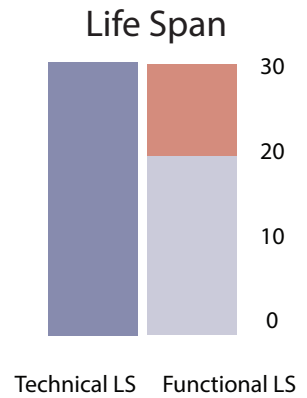
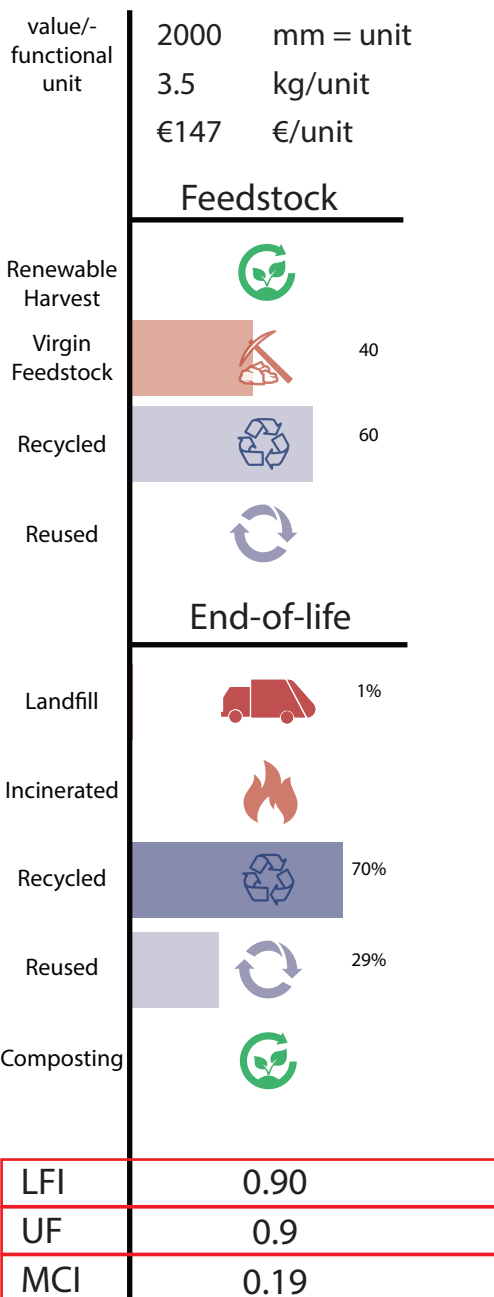
RAINWATER-DRAINAGE - 14.03

The third and last sub-code describes the application of the rainwater drainage for the supermarket itself. This system is made from Loro-X piping. The type of piping used is steel piping, they are connected in each other through insertions. The piping itself is connected to the existing structure through clamps, which can be screwed into the brickwork. Steel has got the interesting property that it can be fully recycled. Currently 60% of the stainless steel used in the world is made from scrapped steel. This amount is difficult to increase, the amount of scrap from deconstruction and demolition is too low to satisfy demand. Steel is also 100% efficient in its recycling and steel can be up-cycled even(Bureau of International Recycling, -). The price for these pipes differ per element. For the example the Loro-x pipe with a diameter of 100 mm was chosen. The Pipe is 2000mm in length. Completely made from steel. Per meter these pipes cost €147,-(Loromeij-Goor, 2018).



Fig. 35: Loro-x product(LORO, 2018)

Material Circularity Indicator



Recycling Efficiency
100%

5.3. STRUCTURE

As the second layer in Steward Brands diagram the structure is built up from two parts usually, the foundation and the load-bearing elements. These parts are usually impossible or expensive to change, if you want to keep the building around it stable. This structure can be around 30 to hundreds of years (Brand, 1994). Though as was shown in the first chapter, most buildings are demolished somewhere between their sixtieth or ninetieth year (Adams, Osmani, Thorpe, & Hobbs, 2017). In the Lidl's Specification five codes can be found for its structure. Each of these provides a part of the complete load-bearing structure. The following five codes covers all aspects:

- 20 Funderingspalen en damwanden
- 21 Betonwerken
- 22 Metselwerken
- 24 Ruwbouwtimmerwerk
- 25 Metalen draagonstructies

20 Funderings palen en damwanden

After the site is prepared the next step becomes building the foundation. As shown under code 20 there are three types of piles used by the Lidl for the building foundation. All three of the piles are made from a combination of steel and concrete for the example the first two will be examined. The first pile described is the prefabricated concrete pile (20.02), the second is the concrete screwed pile (20.03). The first two piles, prefabricated and screwed, have the same end of life scenarios and life-cycle (NIBE, 2018h, 2018i). Because all these inputs are the same, this results in both the piles having the same LFI and MCI. While weight is an important factor, it's only important when examining the full assembly or when comparing transport costs. Neither the full assembly or the transport cost are taken into account. Concrete is a curious material, though it has a long life cycle and it is easy to produce. It doesn't fit in the circular design approach. The problem with concrete is the scenario's at its end of life scenario's. As shown in research, new concrete can only exist out of 20% of recycled aggregate out of old concrete (Etxeberria, Mari, & Vazquez, 2007). To recycle a concrete floor you'd need four new floors. This means most of the concrete will end up as either road filler or foundation of new buildings. This shows concrete only has a 20% recycling efficiency, resulting in the waste being down-cycled after its first use. These are also the two cases which will be examined for the foundation. The first case is the scenario in which there is 0% recycled feedstock in the piles, the second case is 20% recycled feedstock in the pile (CALDURAN, 2011).

Even though they have the same end-of-life scenarios their assembly is completely different. The first concrete pile is made off-site. Through vibrations the pile is driven into the ground on a stable sand layer. The top of the concrete pile is then demolished, exposing the rebar for at least 0.4m. This rebar is used to connect the pile to the concrete foundation beams, which are poured on-site (20.02.08). The concrete screw pile is made by drilling a hole with a hollow drill. This drill is then filled with the concrete and rebar. As soon as the pile is set the top 20 centimetre is demolished to lay the rebar bare which will be integrated in the foundation. The utility factor for

Material Circularity Indicator

The materials for the foundation are all in the Technical cycle, no biological materials are used. Both scenarios show that there is not much circular about concrete. There isn't an economical method to fully recycle concrete. This contributes to the final material getting a score of insufficient.

Disassembly Potential

In both methods the rebar is set into the poured concrete. This incorporates the concrete piles into the foundation beams, making it a monolithic structure that can't be disassembled. The only options for the foundation is demolition, turning the whole structure into aggregate. The only positive scores it gets is on the Life-cycle Coordination, the long lasting function is combined with a material which has a long technical service life.

FOUNDATION PILES - 20.02



Fig. 36: Prefab concrete pile(ijb groep, -)

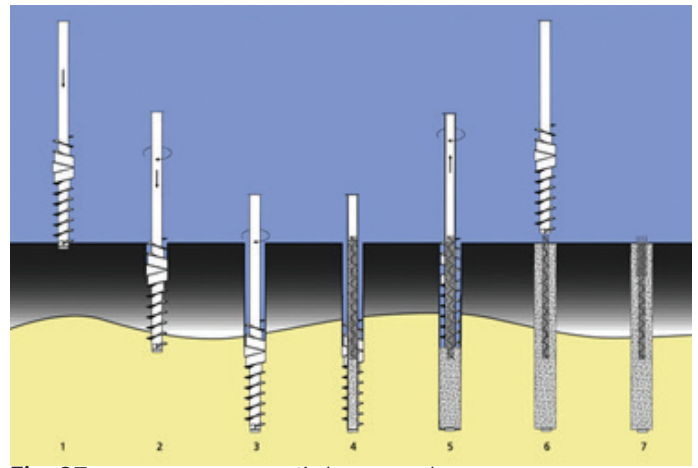
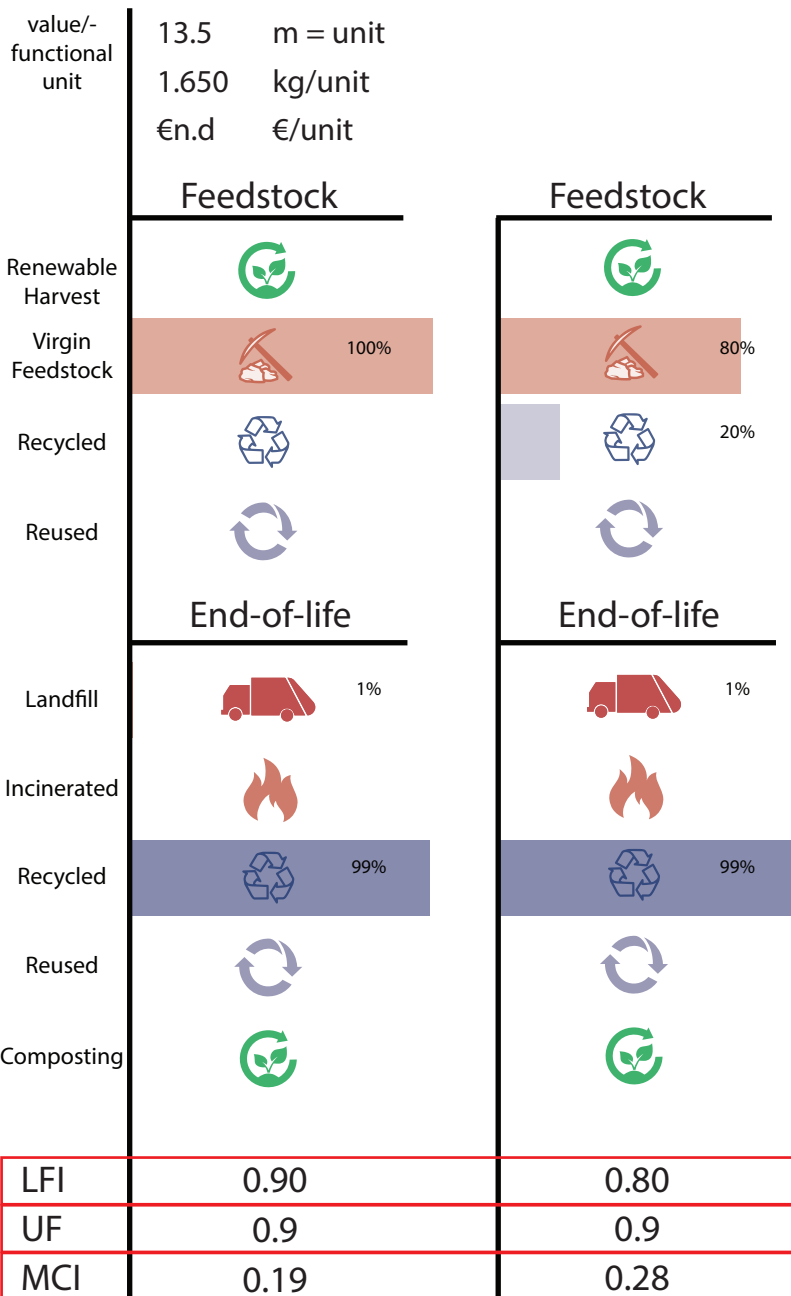


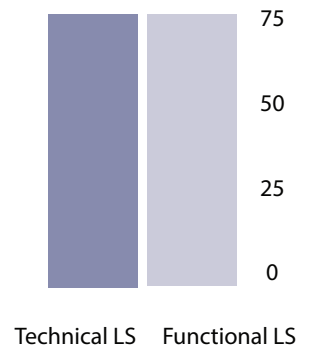
Fig. 37: Concrete screw pile(Vroom., -)

Material Circularity Indicator

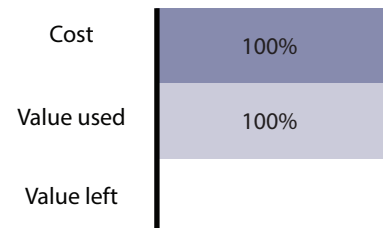
0% recycled feedstock 20% recycled feedstock



Life Span



Value Potential



Recycling Efficiency

20%

21 Betonwerken

The next step within the assembly of the structure are the concrete works. A multitude of codes are about this one material. Two main divisions can be found. On-site poured concrete (21.04) or prefab concrete(21.10). This concrete has the same issues as described for the paragraph for code 20. The methods for recycling concrete make the only end-of-life scenario down-cycling.

21.04 Beton

This isn't reflected directly by the second grade, the MCI. Though it is a very linear material concrete has a long life span, this lifespan can be 100+ years. When compared to structures with the same function and different materialisation it performs better, these structures usually last for 75 years(SBR, 2011). All data for the inputs is taken from the NIBE database (NIBE, 2018a), except for the efficiency of the recycling process. This recycling efficiency is taken from the report by Etxeberria, Mari and Vazquez (2007). This can also be seen in the calculation of the Material Circularity Indicator. It scores the same as the foundation piling. The score is the same as the concrete is dependant on the technical life span of the foundation piles. Again two scenarios can be distinguished. Either no recycled feedstock is added to the concrete or recycled feedstock is added up-to 20% of the total feedstock. Under code 20.02 it was described that concrete can't exceed a feedstock of 20% recycled materials. If it exceeds that amount, research has shown that it's technical performance lowers. The disassembly potential for this type of flooring doesn't score high either.

There is no option for disassembly and reuse. For the concrete that is poured on-site the Disassembly Potential is low. The floor becomes a monolithic structure which leaves demolition as the only scenario. The Disassembly Potential for the prefab concrete greatly depends on the eventual implementation in the construction. The hollowcore (21.10.02) is connected on-site with a concrete top layer. This again makes the plate a monolithic element. This is the main issue that keeps occurring with most of the used concrete in the Lidl's design. This again is what establishes the score of the flooring as Insufficient, both from a reuse and an end-of-life scenario there is no decent option.

21.10.04

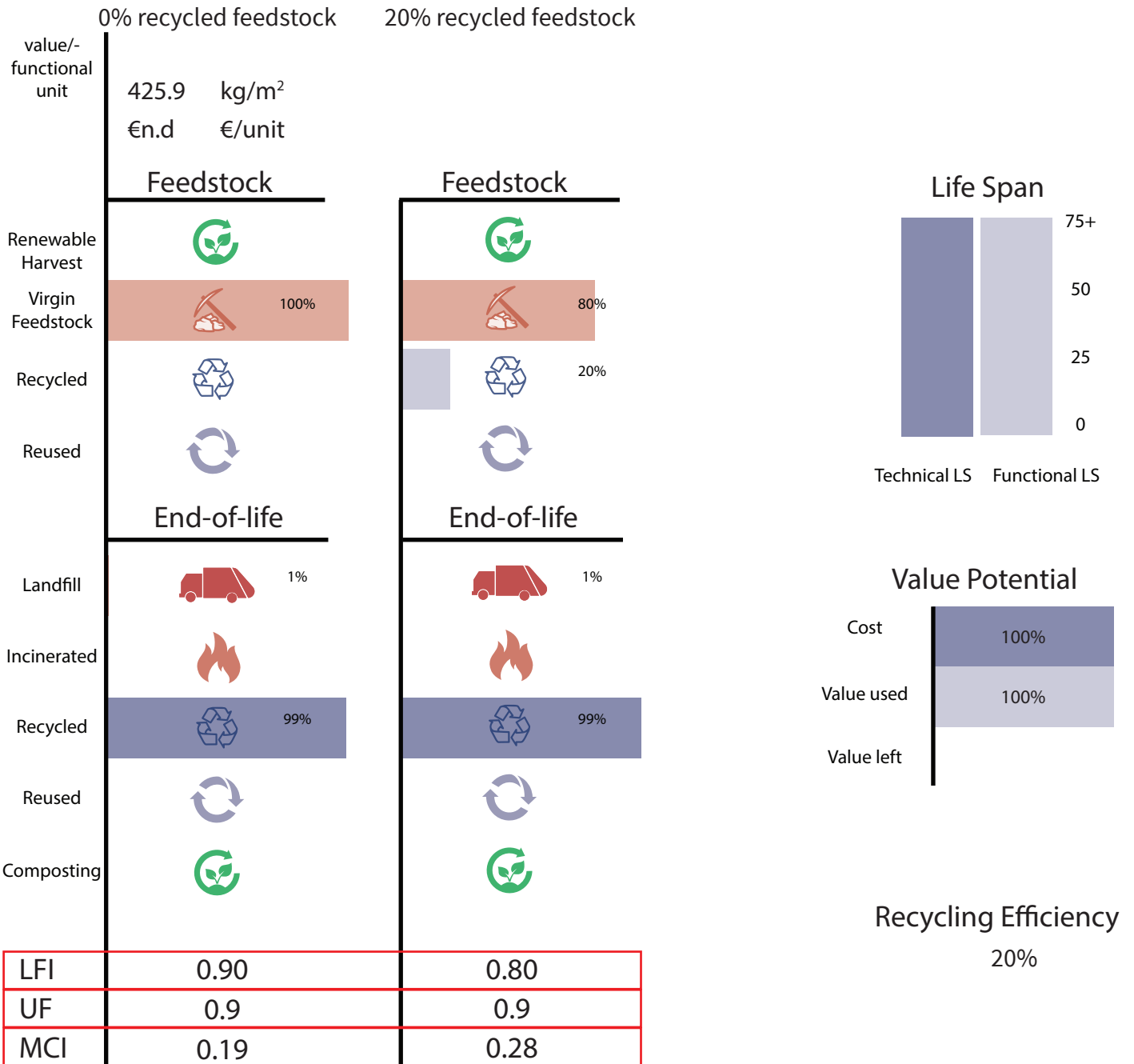
The only concrete material that does get an alright score are the prefab plates, which are described in sub-code **21.10.04**. These plates are used as street tiles. These tiles are placed in sand, due to their weight they are impossible to move without equipment, while the sand provides a stable basis and ensures the plates don't move. With equipment they can be removed and re-used on another site. While still not having a great end-of-life scenario at least there is an option for reuse if a site becomes obsolete.

POURED CONCRETE - 21.04



Fig. 38: Concreting flooring Lidl main office (FaberBetonpompen, 2012)

Material Circularity Indicator



22 Metselwerken

22.02 Kalkzandsteen, vuilwerk

Sand-lime bricks is made from just three materials, chalk, sand and water. Each of these three materials is available in abundance on our planet. These materials are still all within the technical cycle as they aren't renewable sources. Though abundantly available a recycling process needs to be in place to ensure the waste materials aren't landfilled at their end-of-life. Calduran has started recycling old sand-lime brick, they currently employ 20% recycled feedstock in their bricks. Sand-lime bricks consist out of 90% sand, 9% lime and 1% water. The materials are added together, in an autoclave oven the materials are combined into the bricks (kalkzandsteen.nl, 2018). In the case of Calduran the recycled feedstock is used as a substitute for the sand (CALDURAN, 2011). For the recycling process the bricks are grounded up into fine sand. Only pure bricks can be used, any impurities caused by the glue, cement or adhesive used will contaminate the material. This shows there is a potential for recycled feedstock in the material. Though currently only a 20% recycled feedstock is achieved, according to them there isn't enough waste to suffice for a higher recycled feedstock. These bricks are called the Caldubo bricks, these are also the ones employed by the Lidl. As can be seen under this code in the Specification.

The recycling process shows possibilities for a circular material, as sand can be fully replaced there is an option for 90% recycled feedstock. This is why the material receives a decent Linear Flow Index, being close to a circular material. An issues arises when the actual functional life span is compared to its technical life span of the product starts to be taken into account. This same problem also causes the material to have a bad score for the Disassembly Potential. The material has, compared to other construction material, a decent technical life expectancy, of a 100+ years. The issue is that the system is not flexible at all. No functional changes can be made without completely destroying the bricks.

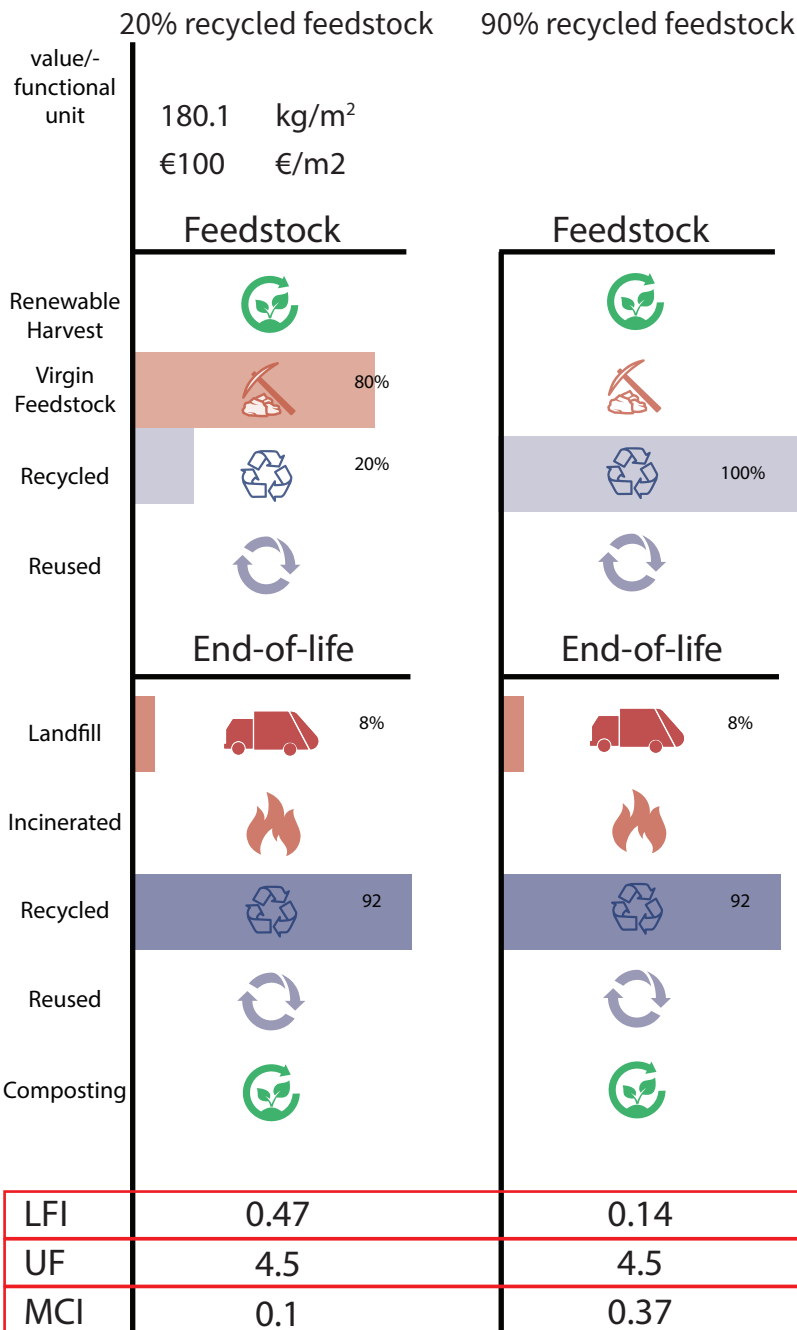
All technical inputs are taken from the NIBE database (NIBE, 2018b). This shows the first great loss in value of the materials. The sand-lime bricks are primarily used in the support for the facade or the indoor walls. The support for the outside walls loose two thirds of their value, even if it's around for a long time like 20 years (Lidl, Personal communication, 08-06-2018). It costs around €85-125 to build a square meter of sand-lime brick wall (Offerteadviseur.nl, n.d.). The adhesives used prevent deconstruction, the only option becomes demolition. The calculations show the result for two cases. The first is the score for the current amount of recycling, the MCI for a recycled feedstock of 20%. The second score is even if the feedstock was of 90% recycled materials as that is the maximum recycling potential that can be achieved with the replacement of sand with recycled feedstock. Because of this the MCI score isn't great, and the overall system gets an insufficient score. A more flexible and deconstructable system needs to be used to allow for easier reuse, especially when it's applied to a fast changing layer, like Skin or Space. The plates are attached in a way that makes them easily reusable

MASONRY SAND-LIME BRICK 22.02

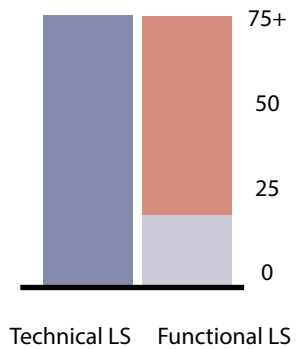


Fig. 39: Kalkzandsteen binnenmuur (Molitor, 2008)

Material Circularity Indicator



Life Span



Value Potential



Recycling Efficiency

90%

24 Ruwbouwtimmerwerk

24.01.01

Wood is the first material which has the possibility to be fully embedded in the biological cycle. As a renewable resource the sustainability is highly dependent on its origin. The wood the Lidl uses has to be from PEFC or FSC certified forests. The definition for both these grading methods is (PEFC, 2011):

“ The certification of forests to credible, independently verified standards of responsible forest management.”

Both are recognised and acknowledged equivalently by the European Union. The production process, which prepares the wood for the construction industry, determines in what cycle the wood will emerge after its manufacturing. The chemicals which are used to make the wood mould and insect resistant, usually result with a product within the technical cycle. While biological solutions exist many compounds used are still toxic. Because of this the wood's only option is incineration at its end-of-life. Renewable materials slowly lose quality over its technical life span, the material has a finite life. When its technical service life is over the wood gets cascaded into a lower value product, beams usually become particle board (Maccarini & Avellaneda, 2012).

24.01.05

The first product described are the plywood plates used. Plywood only contains two elements, wood and an adhesive. The glue determines the quality of the final particle board. Three different classes can be distinguished. Each higher class uses a stronger adhesive to glue the plates together.

- Class 1: inside in dry applications.
- Class 2: outside where it's covered or protected
- Class 3: outside, uncovered and unprotected

These adhesives are an example for materials that shift the wood, from the biological to the technical cycle. When biological adhesives are used the product can be cascaded into a different function and eventually composted at its end of life returning it to the biosphere. For this specific reason, a lot of research is done on biological adhesives (Buddi, Muttill, Nageswara Rao, & Singh, 2015), tests already show that they can already be applied in class 1 applications (Huang & Li, 2008). The materials required for class 3 applications are still only available in the technical cycle. Though based on biological materials, the MCI of the plywood plate is low. The length of the life cycle depends on the application. While class 1 multiplex lasts for 25 years, class 3 multiples can last 75 years due to its higher grade adhesive.

The disassembly potential for the material is decent. Connections with the rest of the system is made by using screws or staples. These connections are reversible and allow the plates to be reused or re-manufactured. This is the reason why the plywood gets a partially sufficient rating. While the construction methods employed are great for disassembly and reuse, the material itself isn't circular. The solution is shown in the second case, which represents a material in the biological cycle. Their score on the value potential is kept similar, as the material management strategy of the Lidl needs to change before it can make full use of its remaining value, this will also greatly increase the MCI.

All these notes also apply to the rest of the codes described in the chapter on wood products. '24.02 Houtwerken' and '24.04 HSB elementen' both have great potential for circularity, but currently they receive the same score as the plywood plates. They can be made fully from the biological cycle, but currently they are used to short.

PLYWOOD - 24.01.01

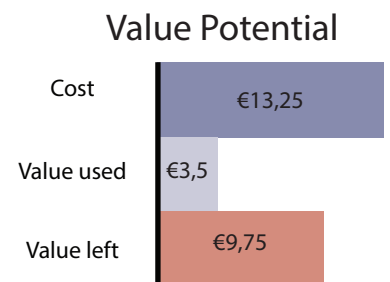
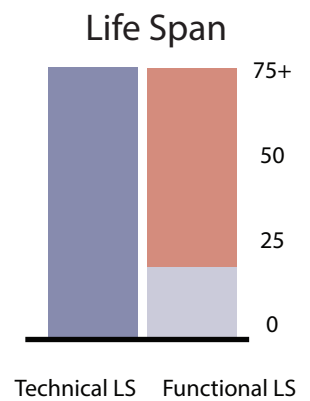
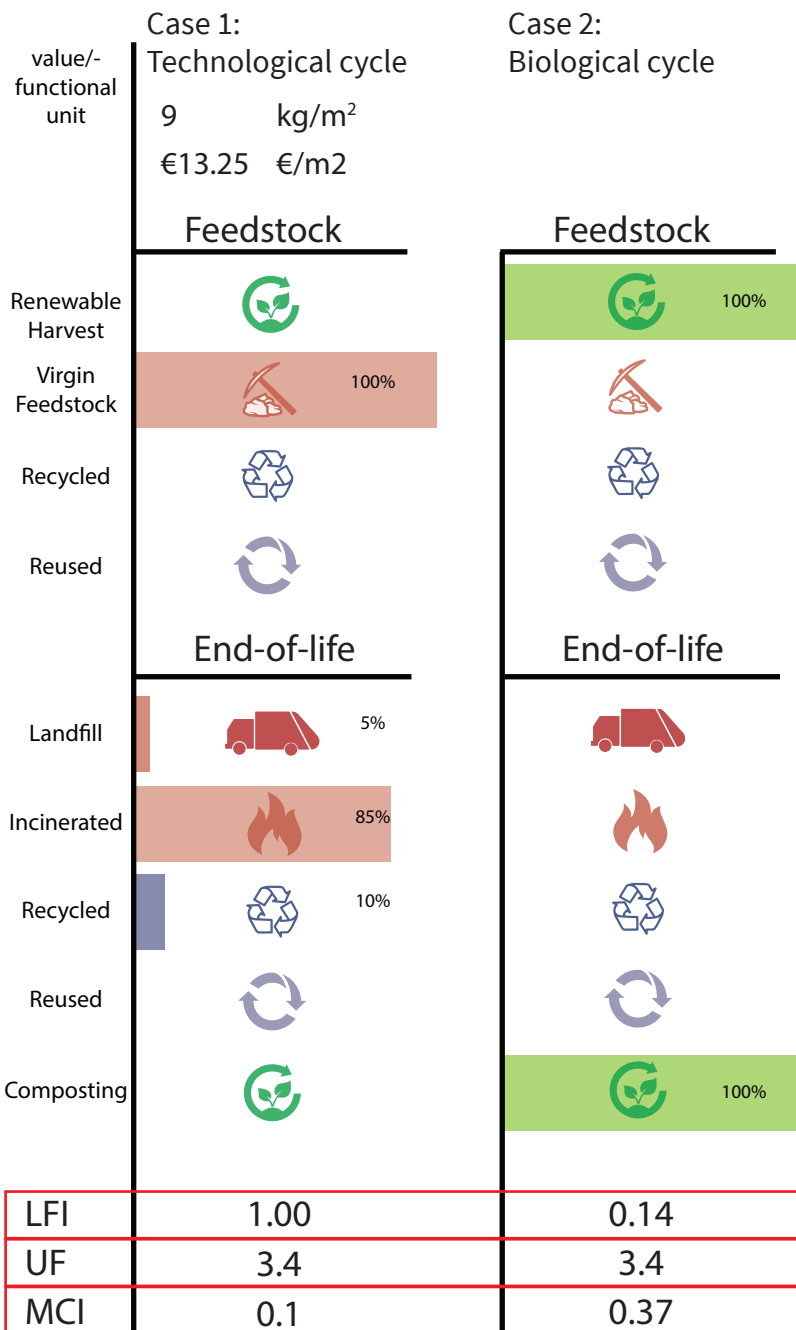


Fig. 40: Lidl standard design, plywood finishing (source: Lidl design)



Fig. 41: Different sizes plywood (Cypers, n.d.).

Material Circularity Indicator



Recycling Efficiency
0%
Potential for material feedstock in a cascaded cycle

25 Metalen Draagconstructies

25.02 Staalconstructiewerk

When examining the load-bearing structure of the Lidl supermarket, the first thing to note is that only one material is used, is steel with a thermally applied zinc layer. Within the steel structure there are over 14 different sizes of beams used. Among these 14 different sizes of beams there is a multitude of irregularities, a multitude has extra flanges or profiles welded on to them. These differences in beams impedes easy deconstruction and reuse. The steel which is visible to the public, gets an extra polyester powder coating. The coating doesn't lower the eventual quality of the steel, the coating is lost at the end-of-life unfortunately, it can either be burned off or sanded off.

Steel is an exceptionally durable material which can be reused, re-manufactured or recycled without many issues. On many levels it's a very interesting building material. Research by the MRPI has shown that steel is one of the few building materials that can be fully recycled and, because of new techniques, even up-cycled. (MRPI, 2013)

Product	Hergebruik/	Recycling
balkstaal	49 /	51
lateien/damwanden	12 /	87
binnenwanden	12 /	87
kozijnen	12 /	87
dak-gevelbekleding	29 /	70

Fig. 42: Percentages recycling and reuse, steel(MRPI, 2013)

For steel beams, reuse is currently already at 49% in the Netherlands. For other varieties of steel this reuse is lower. The feedstock of stainless steel consists for 60% out of scrapped steel. This amount is difficult to increase, the amount of scrap from deconstruction and demolition is too low to satisfy demand. Steel is also 100% efficient in its recycling and steel can be up-cycled(Bureau of International Recycling, -). There is one issue with the use of steel, due to its recycling efficiency it's not possible to improve the amount of recycled feedstock. All scrap available is already applied to the feedstock, steel doesn't reenter the cycle as scrap often, it keeps cycling for decades, far longer than its predetermined technical service life (Yellishetty, Mudd, Ranjith, & Tharumarajah, 2011). The only gains that can be made is through raising the re-usability of your steel even further.

For the load-bearing structure the Disassembly Potentials calculations are not difficult to apply. As it is the first system which is completely made up from mechanical connections, the construction can be completely deconstructed at the end of it's functional life. The Lidl makes it more difficult as there are 14 different types of beams used within their design. This eventually results in over 85 different lengths and types of steel beams used within their design, as can be seen in the drawing FIL_CON1 in the appendix A.

STEEL LOAD-BEARING STRUCTURE 25.02

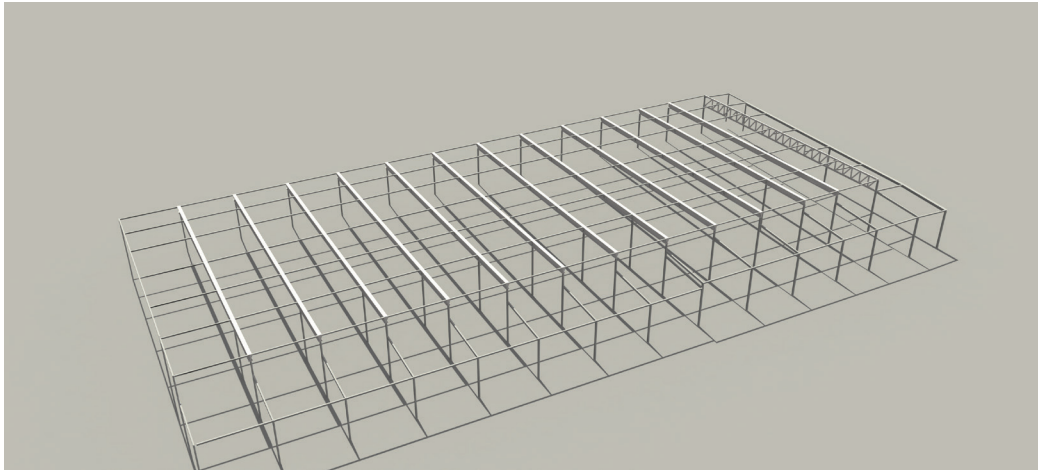
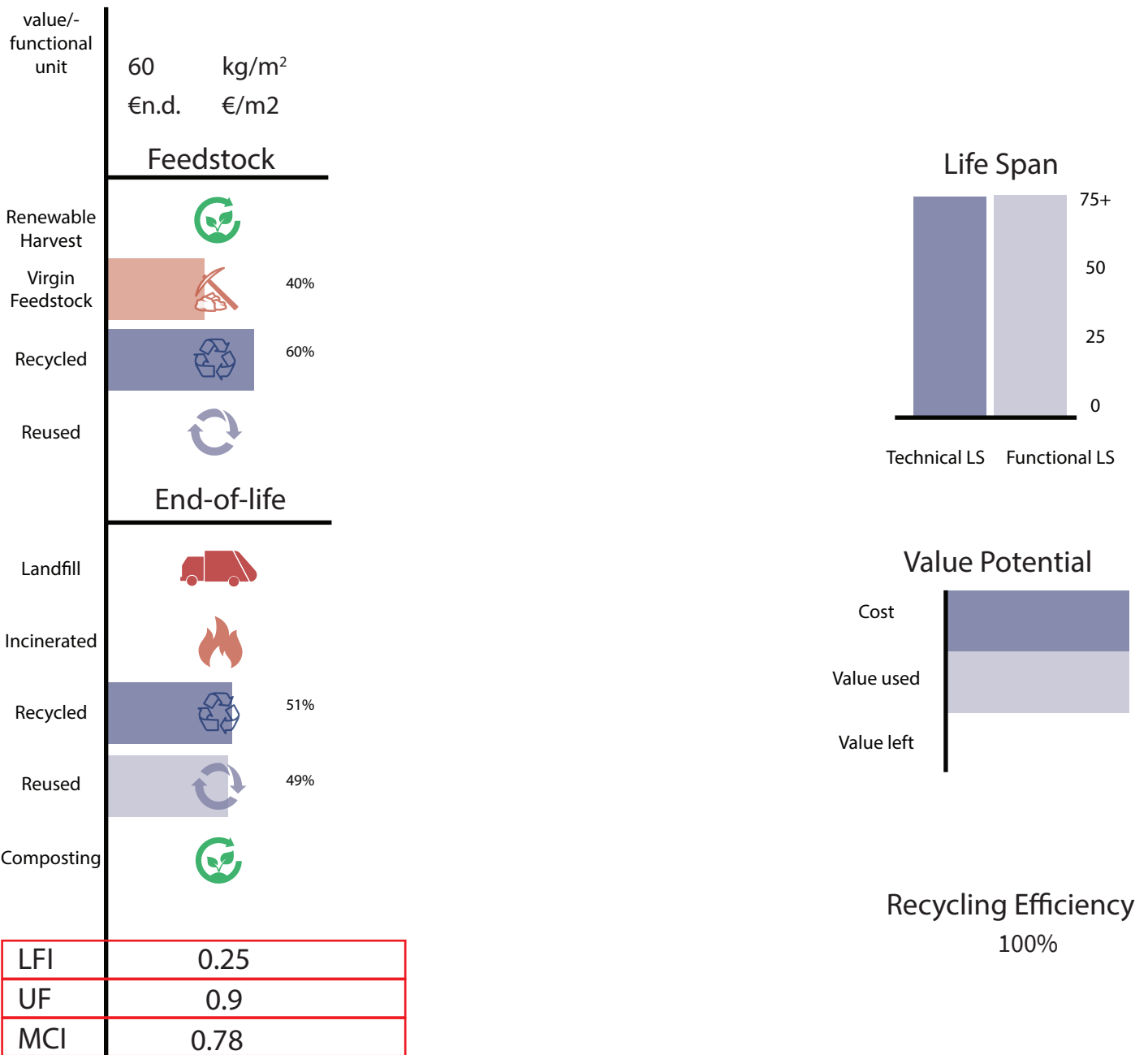


Fig. 43: Lidl 's standard load-bearing structure: (source: own image)

Material Circularity Indicator



5.4. SKIN

The third layer within the Steward Brand model is the Skin layer (Brand, 1994). Dependent on the construction changes this layer almost every 20 years. The skin contains many functions but it's based within the notion that the skin divides inside and outside. This layer has to endure the outside conditions, due to this the layer changes more often than the previous discussed layers. The skin also changes to keep up with innovations and fashion.

22.02 Baksteen, schoonmetselwerk

Brick walls consist out of two materials, the bricks themselves and the mortar that keeps them in place. Bricks are only a sustainable material if they can fulfil their technical service life. This life is usually far longer than their functional life. Because of this reason it is important to ensure the reuse potential for the masonry (Nordby, Hakonsen, & Hestnes, 2009). The possibility for reuse of the bricks is mainly determined by the strength of the mortar applied. When the mortar is stronger than the bricks cleaning becomes difficult, as the first part to fail will be the brick. The mortar used by the Lidl is on a cement basis, this is usually stronger than the bricks themselves. The Bricks have a yield strength of 15 N/mm² (den Daas, 2017).

This means only 70% has the possibility to be recycled, over 30% lost during demolition. The brick is a long lasting material which performs well. The issue is that there is no positive end-of-life scenario. The brick gets destroyed during its demolition, NIBE sees the transformation from brick into granulate as recycling. In reality there is no real option to use old bricks as recycled feedstock for new bricks, reuse is the only option. Because of this reason brick doesn't get a great score for its circularity. It receives an insufficient just like the rest of the masonry. The brick currently in use should be kept in use as it's a very durable material.

The Disassembly Potential for the standard masonry is pretty much non-existent as it is all glued together in one monolithic wall. The functions between the masonry on the inside and on the outside are stuck, they can't be changed or maintained as they are encapsulated by the masonry. It is a very static assembly. It is impossible to add extra windows, or a different kind of insulation without destroying either the outer, or inner wall.

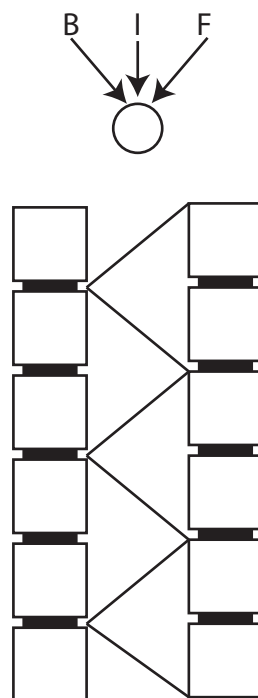


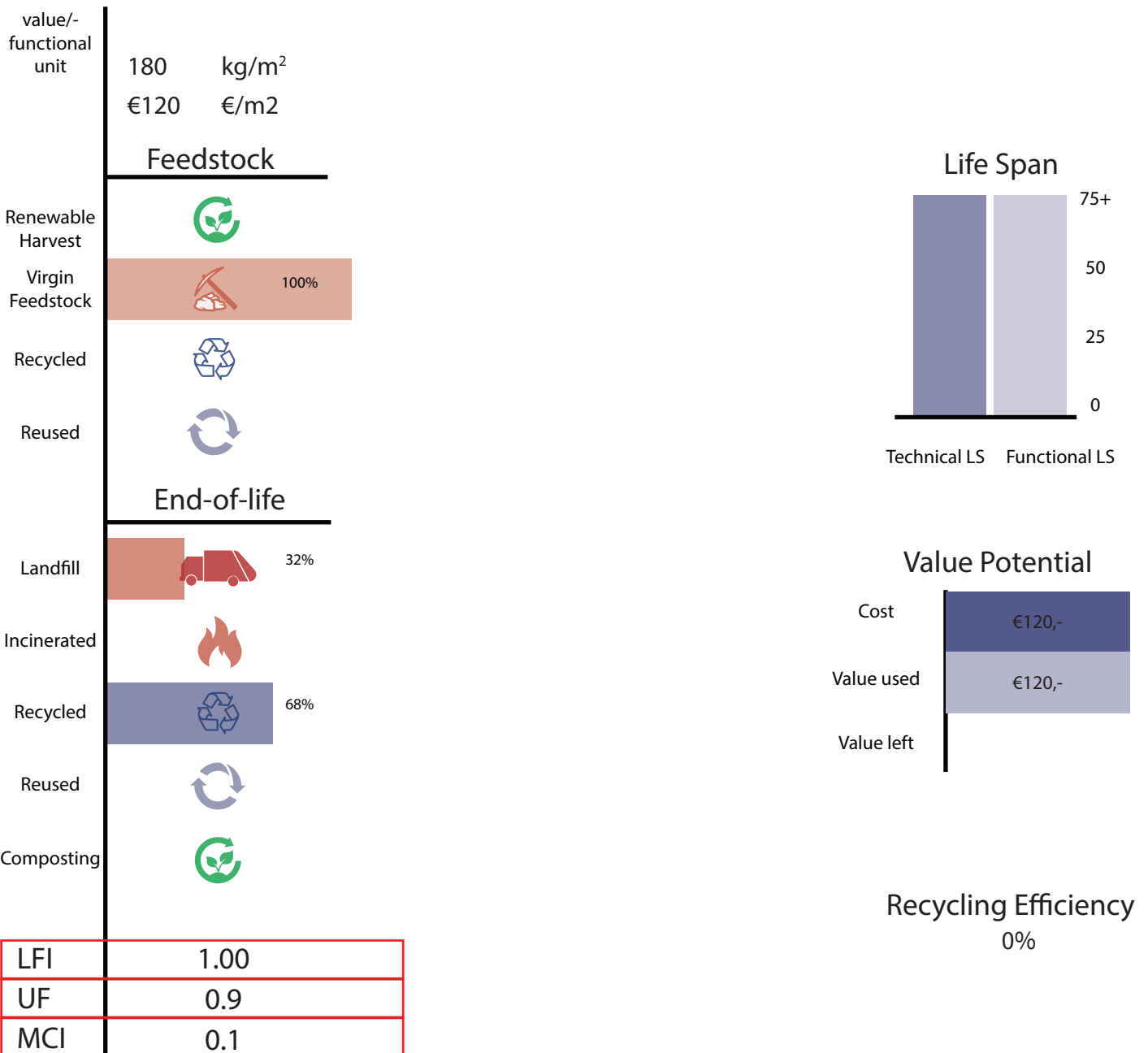
Fig. 44 Fig. 44: Masonry wall, sand-lime brick load-bearing, PIR insulation, Clay brick finishing.

MASONRY CLAY BRICKS - 22.02



Fig. 45: Lidl standard design, brick masonry (source: Lidl design)

Material Circularity Indicator



22.03 Spouwmuur isolatie

The insulation mainly applied throughout the whole supermarket design are PIR foam boards. PIR is also known under its full name Polyisocyanates. The PIR compound is formed by combining poly-hydroxyl and isocyanate. These two react in a 10 step process until only the PIR is left. The process is quite volatile and can result in more than 6 different types of plastic, in just a single block of PIR. Because of this PIR isn't a pure material, it's inherently contaminated (Behrendt & Naber, 2009). These different plastics makes recycling almost impossible as all six have different chemical and thermal characteristics. This makes recycling an unattainable solution, when examined from an economic point of view. The only way to recycle them is through grinding it up to flakes and using an adhesive to glue these flakes together. This recycling system can only use 90% of the resource and ends up on a lower quality than the original, often used as floor insulation (Yang et al., 2012).

The PIR's end of life scenario is either the incinerator (75.1%) or the landfill (19%) the 5.9% that actually gets recycled according to the NIBE data are the aluminium layers between which the PIR is mounted, and the other recycling is the down-cycling previously explained (NIBE, 2018e). The connection of the PIR plates to the load-bearing wall itself is made through the use of steel fixings. These fixings are embedded in the sand-lime masonry. The seams between the PIR plates are filled with PUR foam to make the whole structure completely air-tight.

The Disassembly Potential of the part is non-existent. This is caused mostly by its placement in the wall system. The PIR is located between two layers of bricks, this is shown in Figure 46. The only opportunity to remove the PIR insulation is by demolishing the outer brick layer.

CAVITY INSULATION - 22.03

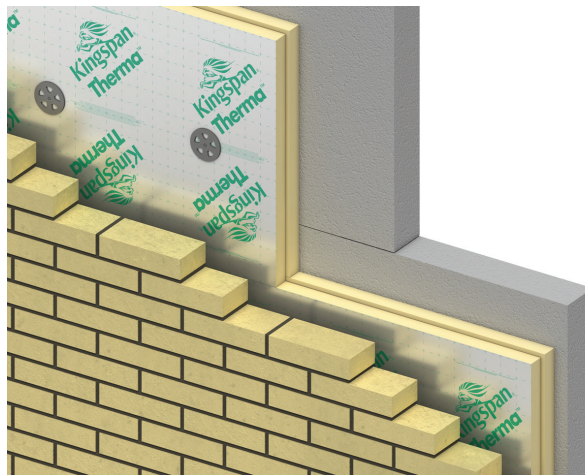
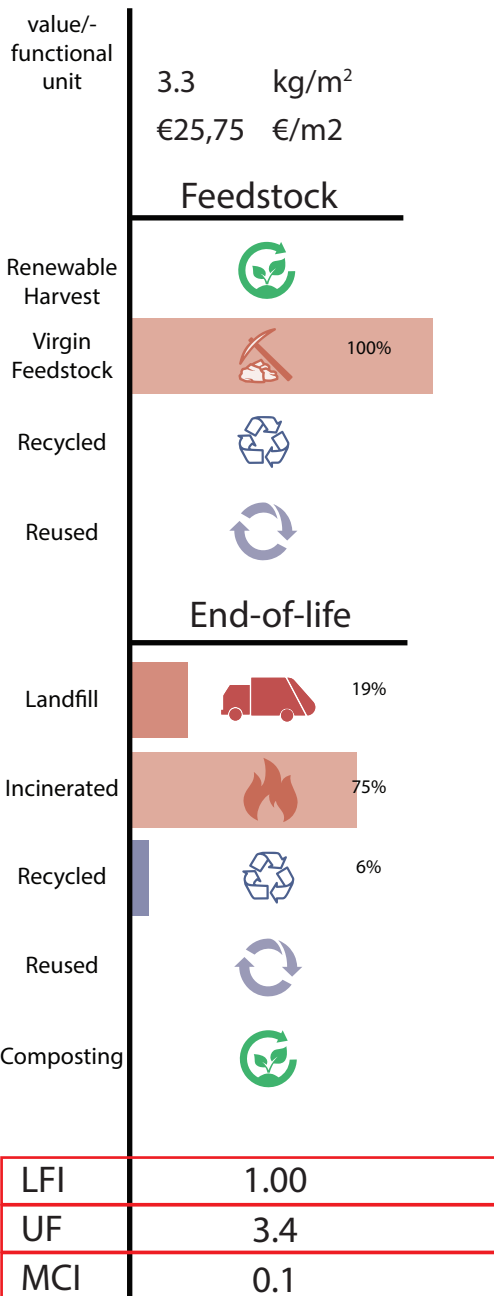
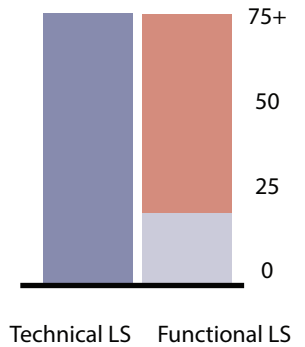


Fig. 46: Kingspan cavity insulation (Kingspan, n.d.)

Material Circularity Indicator



Life Span



Value Potential



Recycling Efficiency
0%

25.04 Staaldak

The roof is constructed from steel as well, steel plates to be precise, these will all be laid down flat, with on top of them insulation to provide the necessary angle. The connections are made through rivets, these prevent easy disassembly at their end of life, roof parts can't be reused easily because of this system. The only method for disassembling is drilling through the rivets.

The material itself has the same benefits as the steel beams, though the reuse potential is lower the steel plates already contain a high amount of recycled feedstock and can be fully recycled (Bureau of International Recycling, -)

The plates have a mismatch between functional life span compared to their technical service life. Most of the value is left in the material. As a result out of the €7,- per m² paid, less than €2,- is actually used. The product itself isn't very linear as the recycling and reuse potentials are high. The short functionality reduces the Material Circularity Indicator by a lot as the result of the fast obsolescence.

There is one issue with the use of steel, due to its recycling efficiency it's not possible to improve the amount of recycled feedstock. All scrap available is already applied to the feedstock. The only gains that can be made is through raising the re-usability of your steel. (Yellishetty, Mudd, Ranjith, & Tharumarajah, 2011)

CORRUGATED STEEL PLATE 25.04

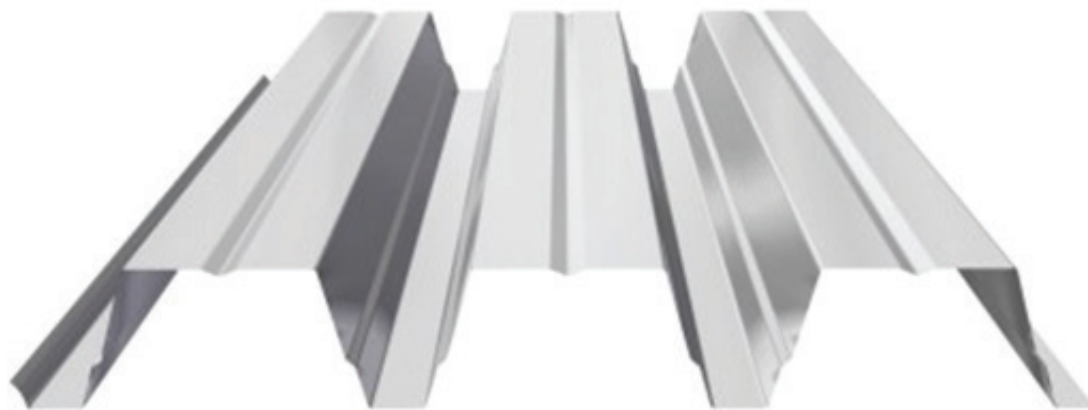
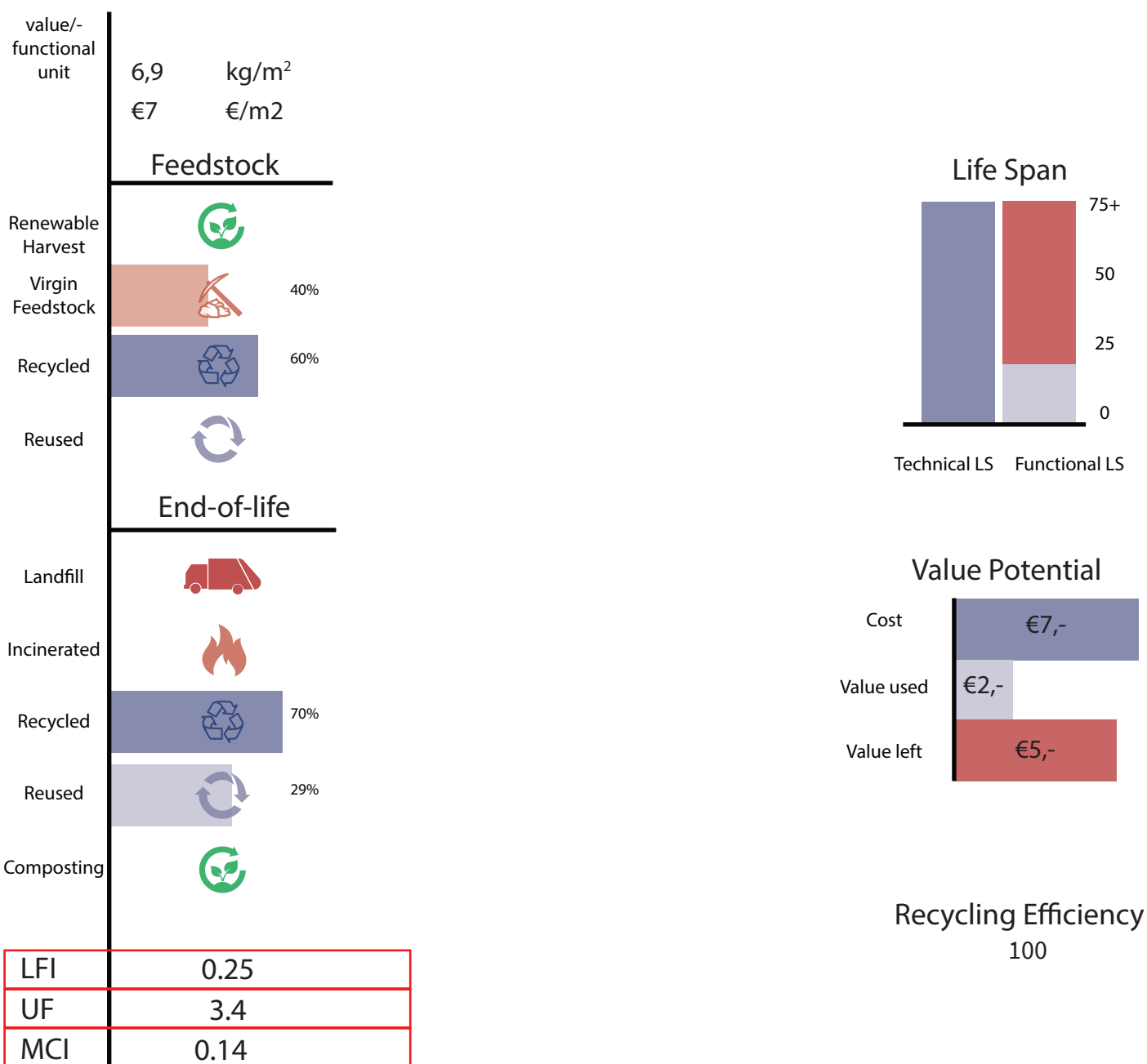


Fig. 47: Sendzimer profielplaat(Hardeman, n.d.)

Material Circularity Indicator



31 Systeembekleden

31.03 Alucobond bekleding

The Alucobond panels, described in the Specification, can have a multitude of build-ups, while the outer material is always aluminium, for the core there is a choice. Either a honeycomb panel or mineral wool. The honeycomb in the panel is made up from aluminium as well. This gives the honeycomb panel a great recycling potential as the only material used is aluminium (Alucobond, n.d.). The panel with mineral wool inside has got a lower recycling potential, due to the adhesives the materials can't be mechanically separated and will need further step to bring it back to its basic components.

This supplies us with two materials, each with a different MCI, both influence the MCI of the total product. Both the products have an life expectancy of 40 years(NIBE, 2018k). The product has a theoretical recycling potential of 100%. According to the NIBE database the product doesn't get fully recycled. 5% gets landfilled, 15% gets incinerated and 80% gets recycled. This is a different number when compared to the research done within the construction industry, according to research 95% gets recycled. Aluminium as a material has already got a quite high recycled feedstock, which is 47%. This is almost the same as steel. It also has the same issue as steel, because the products last long and the demand for the material is very high, the available scrap gets completely used up and leaves a gap which needs to be filled with virgin feedstock(Jonkers & Dreijerink, 2011).

The Disassembly Potential for this part is high, though it's just a single cladding layer not all parts of the Disassembly Potential apply. The Interesting part which make the part score high for the DP are the Assembly direction, Connection and Geometry. These three determine the principles for the part. The Assembly direction scores high because the parts can be assembled completely independently. They don't rely on each other for their assembly. The Geometry is completely open, enabling the parallel assembly as well. For the Connections are all reversible, they are all made directly through the use of stainless steel screws. The panels have got the possibility to be reused in a different assembly at their end of life, extending their service life.

ALUCOBOND FACADE PANELS 31.03



Fig. 48: Alucobond facade Multatuli weg, Delft (source: own image)

Material Circularity Indicator



31.04 Lamellen Bekleding

The Lidl applies aluminium blinds in two applications. The first application is the blinds as a façade cladding, the second is for the technical installations, here the Lidl uses the blinds to keep the installations out of the public view. The blinds are made from aluminium by Storax B.V.. The blinds are applied, to a separate steel structure, on top of the roof. The elements are exposed on all sides to the outside weather. The connection between the blinds and the steel structure is a direct one, the blinds are connected through push fit connections. The system itself is screwed directly on the steel structure. This allows the blinds to be disassembled independently and applied to a different structure.

The data for the blinds are taken from the NIBE database (NIBE, 2018L). The end of life scenario for the aluminium blinds according to the database: 3.1% gets landfilled, 4.1% incinerated, 87.3% is recycled and 5.6% is reused. The incineration is applied to remove the coating which is applied to the aluminium. The connection principles applied to the blinds allow them to be disassembled and reused at their end of life. The amount reused at the moment is quite small, with the right management the aluminium blinds, which are still performing as stated, can be reused in a new application. The feedstock for the aluminium is already highly recycled (47%), only outranked by steel (Jonkers & Dreijerink, 2011).

MCI

The Material Circularity Indicator for the product can be calculated with the following data, taken from the NIBE database (NIBE, 2018L):

Weight:	22.6 kg/m
Reuse:	5.6%
Recycling:	87.3%
Incineration:	4.1%
Landfill:	3.1%
Life span:	25 years

DP

The disassembly potential of the part is high, the assembly of the product allows it to be taken apart when the building changes function, the blinds can be reused in another application. Aluminium, when compared to other materials, has a long technical life span. Even though the service life span of the product is 25 years according to NIBE, aluminium as a material doesn't degrade over time, even when exposed to weather.

ALUMINIUM FACADE BLINDS 31.03



Fig. 49: Lidl's aluminium blinds in front of services (source: Lidl image)

Material Circularity Indicator

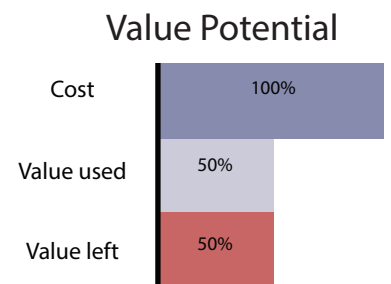
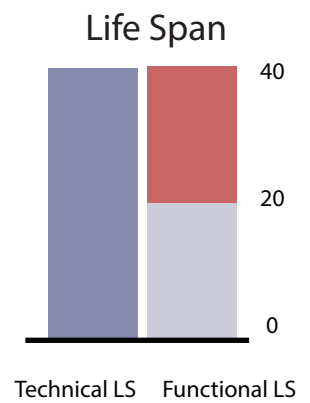
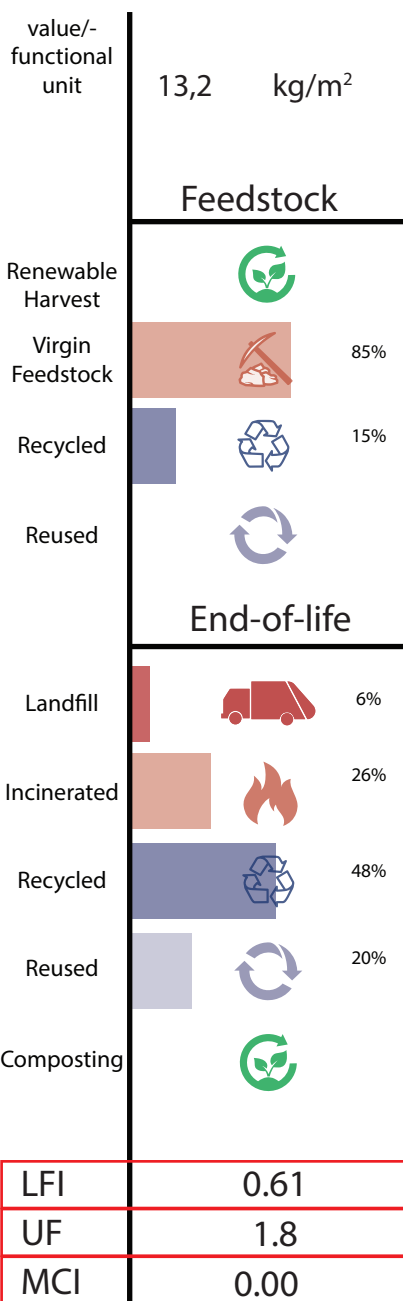


31.05 Sandwich panel

The last product applied to the façade is the Kingspan sandwich panel. The panel consists of two materials, a steel exterior and PIR interior. Through a machine array the steel plate is gradually flattened to a thickness between 0.12 and 0.49 millimetre. The steel plate gets the addition of a layer of glue, this connects the PIR and steel and results in a monolithic panel, from which the layers can't be separated (SABprofil, n.d.). The panels, in the case of the Lidl, are bolted on omega profiles, this allows the sandwich panels to move with thermal expansion, but also to be disassembled at its end of life. The panels can't be disassembled easily into their original components, the only solution is shredding the panel to retrieve the separate materials in that manner. This results in the following end-of-life scenarios for the panels: 6.5% gets landfilled, 25.6% incinerated (which is mostly the PIR insulation), 48.0% gets recycled and 19.9% of the panels are reused (NIBE, 2018m). As can be seen in the data from NIBE, there is a potential for reuse of the sandwich panels. All of the panels are mechanically connected, this connection is made by bolts. The assembly of the panels is fully sequential as all panels overlap each other. This overlap also hides the connectors. The PIR has got inherent recycling issues, for in depth explanation refer to 22.03. To summarize PIR: The only economically viable way for recycling PIR is mechanically, which results in a downgraded material. The feedstock for the PIR is completely virgin as the material can't be recycled, the recycled feedstock is provided by the steel plating. The steel plating is also the largest part of the sandwich panels which will be recycled after the end-of-life.

The panels are easy to disassemble, all connections are made by screws which are reversible connections. This is also reflected by the end-of-life scenario which is prevalent in the Sandwich Panels, 20% of them get reused.

Material Circularity Indicator



Recycling Efficiency

33 Dakbedekkingen

33.03 Voorbehandeling ondergrond, baanvormige dakbedekking

On top of the corrugated steel described under code 25.04, a loose laid vapour barrier. The vapour barrier is added to a structure to regulate the amount of moisture which can move through the layer. These barriers are a necessity in cold climates, they ensure no moisture enters the insulation material from the inside and can condensate in the insulation material, because of the temperature differences. This condensation provides breeding grounds for moulds. The vapour barrier employed by the Lidl is a Sarnavap 1000 or 2000, it's an Low Density Polyethene sheet. The PE-LD foil is laid with a 80 mm overlap, all seams are closed together by tape. The result is a sheet that can be almost completely recycled. Only a small area at the seams become contaminated due to the adhesive. The thermoplastic material is highly recyclable. In practice though, many of the vapour barriers end up incinerated at their end of life(NIBE, 2018d). The end-of-life scenarios for the PE-LD foil are: 10% landfilled, 85% gets incinerated and 5% is recycled.

MCI

For the recyclability of the foil, we refer again to the NIBE database(NIBE, 2018d):

Weight:	0.2 kg/m ²
Reuse:	0%
Recycling:	5%
Incineration:	85%
Landfill:	10%
Life span:	40 years

This results in the following values for the LD-PE:

LFI:	0.975
UF:	1
MCI:	0.123

33.04 Dak isolatie

The roof insulation employed by the Lidl, in their design, is in material the same as their wall insulation. This is PIR insulation between two thin layers of aluminium foil. For the recycling characteristics, of the material, can be referred to the analysis of code 22.03 of the Specification. The end-of-life scenarios for both materials are almost the same, though the accessibility of the roof panels is higher, this results in a slightly higher score, compared to the cavity insulation. The weight of the panels is lightly higher, as the expected thermal resistance for the roof is higher than that of the wall.

MCI

The inputs are taken from the NIBE database:

From the NIBE database(NIBE, 2018e):

- Weight M:	4.8
End-of-life scenario NIBE case:	
- Landfill:	19.3%
- Incineration:	76.6%
- Recycling:	4.1%
- Reuse:	0%

As described by

- Recycled feedstock:	0%
- Reused feedstock:	0%
- Recycling efficiency	0%

Length of material life:

-	75 years.
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33.05 Kunststof dakbedekkingstelsel, mechanisch bevestigd

For the roof finish the Lidl makes use of a FPO (flexible polyolefin) membrane. The membrane is a product from Sika, Sarnafil TS 77-20. This membrane is a single layer of FPO reinforced with glass fibre. FPO is made by using EPR particles combined with an PE (polyethylene) binding agent. In case of the Lidl the sheet is also fibre glass reinforced. The particles come in two varieties, under which the FPO is better known. The materials among which FPO can be divided are TPO and TPV. The difference between the materials is that the TPV is vulcanized. The FPO membrane is connected mechanically to the roof (Steenbrugghe, 2003). Through the use of parkers the membrane is connected directly to the steel plates, this parker goes through the PIR plates and the LD-PE foil. The mechanical connections are all applied in the overlaps between two membranes. The overlap applied between the membranes is at least 120 mm, between the membranes an adhesive is added to ensure water tightness. The membranes can be removed at their end of life, clean membranes, which means without adhesives or other contaminations, can be sent to a recycling plant determined by the supplier. The sheets are 2 by 15 m, because 0.12m on all edges are adhered you lose over 15% of the material to contamination. In the best case scenario 85% of the material could be recycled. The TPO variety is being used by the Lidl, the material has comparable end-of-life scenarios as the rest of the plastics (NIBE, 2018n). The material gets landfilled 9.8% of the time, 83.6% incinerated, 6.4% recycled and a small 0.2% reuse. Though these results are given by NIBE the material has a high potential for recycling. It's fully recyclable but it tends to be easier to incinerate a lot of the time. There is a shift in plastic recycling as it's a contributor to global warming and the exhaustion of the finite resource oil.

MCI

The inputs are taken from the NIBE database:

From the NIBE database (NIBE, 2018n):

- Weight M: 3.2

End-of-life scenario NIBE case:

- Landfill: 9.8%
- Incineration: 83.6%
- Recycling: 6.4%
- Reuse: 0.2%

End-of-life scenario best case (85% recycling):

- Landfill: 0%
- Incineration: 15%
- Recycling: 85%
- Reuse: 0%

As described by

- Recycled feedstock: 0%
- Reused feedstock: 0%
- Recycling efficiency: 100%

Length of material life:

- 75 years.

This results in the following grades:

This results in the following values for the FPO:

NIBE case:

LFI = 0.967 UF = 1 MCI = 0.1297

Best case 85% recycling:

LFI = 0.57 UF = 1 MCI = 0.48

34 Beglazing

Glass has the benefit of being fully recyclable (de Graaf Groep, n.d.), but there must be no contamination of other materials within the glass (Stichting Vlakglas Recycling Nederland, n.d.). The only solution for contaminated glass is to use it in a completely different application, i.e. concrete filler, or the glass must be landfilled. The contamination makes the recycled glass strength inconsistent, or the contamination can damage the machines used to make the glass (Anderson, Braddock, & Hardie, 1998). This applies to all glass, both from consumer and construction industry.

It's difficult to determine how much of the glass feedstock is from recycled sources. Different glass products have a different input, even during the day this feedstock changes. For glass it is possible to make it for 100% out of recycled glass, in practice for packaging glass the recycled content is between the 50% and 90%, in the Netherlands this averages out on around 63% recycled feedstock for glass (Meldpunt Verpakkingen, n.d.).

34.03 Gelaagd glas

The first type of glazing described within the Specification of the Lidl is the layered safety glass. The safety glass is constructed by layering glass and PVB. These are then cured in a pressurized oven. This glass is applied in all indoor doors and windows. In the Netherlands you can bring layered safety glass to the recycling plant if it's got a thickness under 30mm. They'll break it down and try to remove the PVB from the glass as much as possible. The Safety glass can only be brought to the plant, if it's blank glass (Stichting Vlakglas Recycling Nederland, n.d.). This would be an issue for the glass used in the counting area, which is made reflective. These notions make it difficult to determine how much glass can be recycled when examining the safety glass. While the feedstock of the material is of a highly recycled nature, the end-of-life scenario is difficult to determine. Suppliers say the material can be recycled, but in practice it proves difficult to split the PVB from the glass. This results 30% of the material being landfilled, it's difficult to make this part higher (NIBE, 2018o).

MCI

The inputs are taken from the NIBE database:

From the NIBE database (NIBE, 2018o).

- Weight M: 15,0 kg/m²

End-of-life scenario NIBE case:

- Landfill: 30%

- Incineration: 0%

- Recycling: 70%

- Reuse: 0%

As described by

- Recycled feedstock: 63%

- Reused feedstock: 0%

- Recycling efficiency 100%

Length of material life:

- 75 years.

This results in the following grades:

NIBE case:

LFI = 0.335

UF = 1

MCI = 0.699

37 Isolatie

Insulation comes in many varieties, this can also be seen in this chapter from the Lidl's Specification. Within the Specifications chapters, which are discussed previously, it seems the Lidl primarily uses PIR insulation. As PIR provides high insulation for low cost (LIDL, personal communication, 08-06). The Lidl applies different thermal resistance values for the different surface areas. The result is three different values demanded, for three different surfaces:

- Roofs: 6.0 m²K/W
- Walls: 4.5 m²K/W
- Ground floor: 3.5 m²K/W

37.02 Glaswol

The first insulation material described within the Specification is the glass wool insulation. This material is only applied for all penetrations in the roof edge, relating to rain water.

Glass wool is a soft insulating material, the material is produced by heating glass until it's molten. By using rotating and spinning heads the liquid glass is spun into a woolly material. The material can't distribute weight and will need additional construction for that if applied flat to the roof. The material has a few issues, compared to other insulating materials it requires precaution when handling the material (Mens & Werk, n.d.). The Glass wool can be fully recycled at the end of life, the wool already contains up to 80% recycled feedstock. The end-of-life scenarios show a different end, most of the material is landfilled according to NIBE. Manufacturers will usually take their material back, as they can use it as new feedstock.

1. 0,035 W/m.K
2. 40 kg/m³
3. 70-80% recycled glass content (Isover, n.d.).
4. End-of-life: Recycled 10% efficiency 100%, landfilled 90%.
5. Product life 75 years
6. Soft insulating material
7. 45,- €/m³

Material Circularity Indicator

The Material Circularity Indicator can be determined for two scenarios. The first would be the completely linear scenario, where the material is sent to the landfill (NIBE, 2018q). The second scenario is where the material will be sent back to its supplier in full.

From the NIBE database (NIBE, 2018n, 2018q):

- Weight M:	12 kg	End-of-life scenario best case (100% recycling):	
End-of-life scenario NIBE case:		- Landfill:	0%
- Landfill:	85%	- Incineration:	0%
- Incineration:	5%	- Recycling:	100%
- Recycling:	10%	- Reuse:	0%
- Reuse:	0%		

Feedstock

- Recycled feedstock: 0%
- Reused feedstock: 0%
- Recycling efficiency: 100%

Length of material life:

- 75 years.

This results in the following values for the Glaswool:

NIBE case:

LFI = 0.6 UF = 1 MCI = 0.46

Best case 100% recycling:

LFI = 0.15 UF = 1 MCI = 0.87

37.03 Hardschuim

Expanded Polystyrene panels, in short EPS panels, are applied under the concrete flooring. The plates are used as the casing for the concrete. There are difficult to recover as the concrete flooring is poured on top of them. The polystyrene is a thermoplastic, this allows the material to be easily recycled at its end of life. Old insulation gets ground up and is molten back into new polystyrene feedstock. This happens without losing out on its original quality (Devries recycling, n.d.). It has the benefit of already having an established recycling industry. Though the NIBE database still expects the material to be mostly incinerated. As most plastics lost in demolition and ending up together in granulate, it is difficult to separate these plastics after. The only option is either chemical recycling, which currently isn't economically feasible, or incineration. The case, in practice, ends up with the later (NIBE, 2018r). The EPS plates are applied under the concrete flooring. This makes the plates difficult to remove after they are applied. The only option is demolition along with the concrete. The EPS insulation itself has the following characteristics:

1. 0,035 W/m.K
2. 15-40 kg/m³
3. End-of-life: Recycled 10% efficiency 100%
4. Product life 75 years
5. Rigid
6. 55,- €/m³

This can all also be seen within the MCI, as the plates can't easily be recycled fully, even though the efficiency is 100%.

MCI

The inputs are taken from the NIBE database (NIBE, 2018r):

- Weight M: 2.1 kg/m²

End-of-life scenario NIBE case:

- Landfill: 0%
- Incineration: 90%
- Recycling: 10%
- Reuse: 0%

As described by

- Recycled feedstock: 0%
- Reused feedstock: 0%
- Recycling efficiency 100%

Length of material life:

- 75 years.

This results in the following grades:

LFI = 0.95

UF = 1

MCI = 0.15

37.04 Steenwol

The fourth material used within the Lidl's design is stone wool, it has unique properties compared to other insulating materials. The only place currently applied is between the flanges of the steel beams. When you examine the characteristics of the material the first thing that can be noted is that the material is completely inflammable. Rockwool was chosen as a representation for the possibilities of the insulation. They make the insulation from a combination of, basalt, diabase and anorthosite. These materials are all from Vulcanic rock and are in abundant supply on earth(Rockwool, 2015). The technical specifications of Rockwool(Rockwool, n.d.):

7. 0,038 W/m.K
8. 45 kg/m³
9. End-of-life: Recycled 100% efficiency 100%
10. Product life 75 years
11. Soft
12. 92,- €/m³

MCI

The inputs are taken from the NIBE database(NIBE, 2018r):

- Weight M: 5.6 kg/m²

End-of-life scenario NIBE case:

- Landfill: 0%
- Incineration: 0%
- Recycling: 100%
- Reuse: 0%

As described by

- Recycled feedstock: 0%
- Reused feedstock: 0%
- Recycling efficiency 100%

Length of material life:

- 75 years.

This results in the following grades:

NIBE case:

LFI = 0.5

UF = 1

MCI = 0.55

5.5. Conclusion

The Specification contains all information needed for the construction of a Lidl's supermarket. It shows the manufacturer for many materials and connections which should be employed. With this information and knowledge from the NIBE, recycling plants and scientific sources, an careful analysis can be made on the circularity of the Lidl's current supermarket design. With this we can determine their current position and on which places easy gains can be made. The Specification was analysed with the three main principles of the Circular Economy in mind, the most prevalent principle in the analysis was: Keep products, components, and materials at their highest value and in use. The individual codes each got an rating. These can be divided into three categories:

- Sufficient
- Partially sufficient
- Insufficient



Fig. 50: Specification scores (source: own image)

There are a multitude of materials and construction principles in the Specification, which aren't circular at all. The parts with the lowest scores are almost all in the horizontal surface areas. The floor and the roof score especially bad. The floor gets a bad score due to the monolithic nature of the concrete used, the roof because of the plastics which can't be recycled and the build-up which make disassembly to costly. The analysis overall shows a great potential for the Lidl to extract more value out of the building materials used. While paying full price for the material, many of the materials only use less than a third of the value for which the Lidl paid.

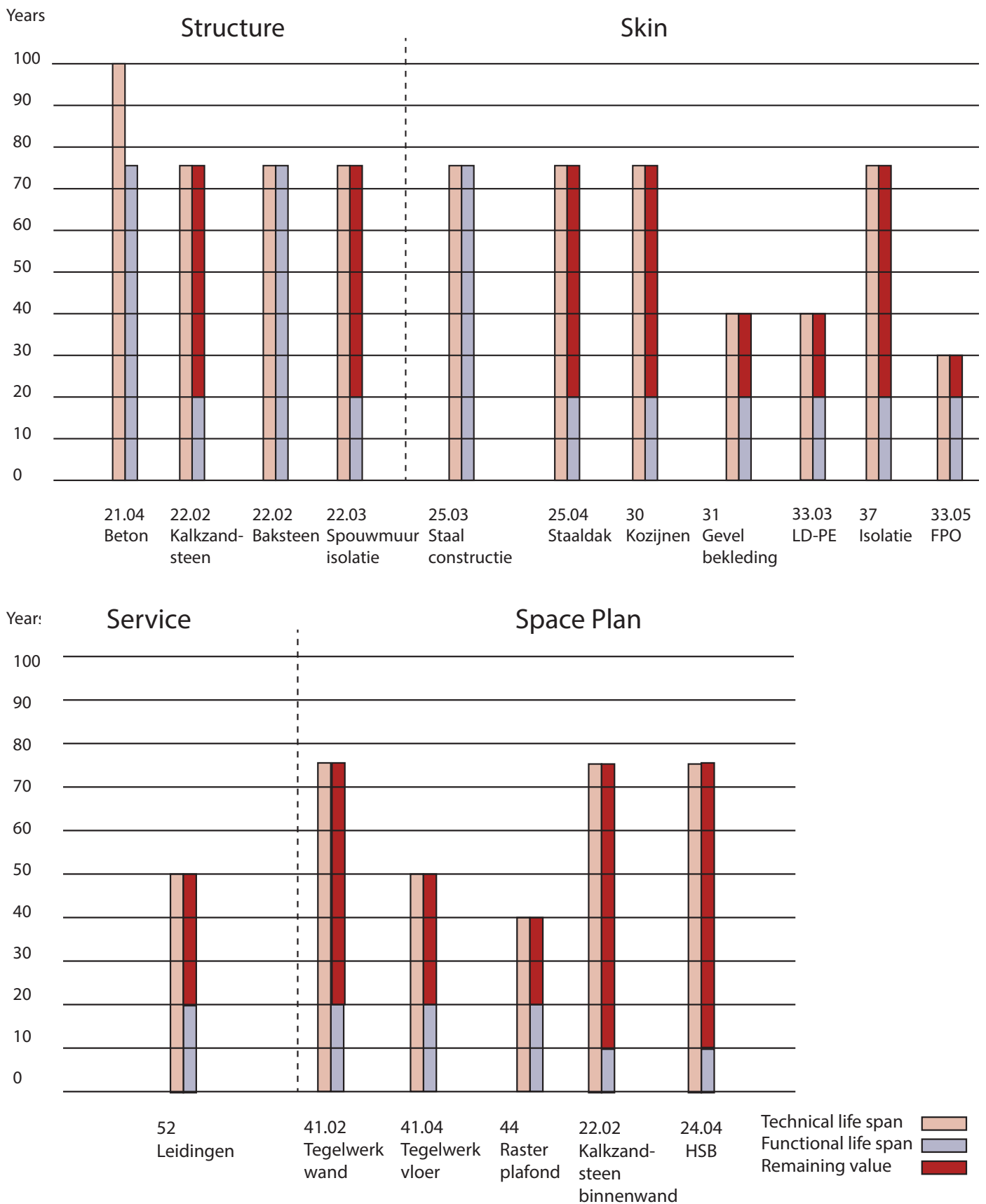


Fig. 51: Technical service life span compared to Functional service life span. (source: own image)

For the actual redesign the roof was chosen. The roof doesn't receive the worst score out of all the building systems, it does however contain a multitude of different functions, all fulfilled by different materials. It also shows what is currently possible with circularity for the Lidl. It is a relatively fast changing layer, with fast changing functionality, which would benefit from adaptability.

6 HOW CAN A BUILDING SYSTEM, AS DESCRIBED IN THE SPECIFICATION, BE REDESIGNED INTO A CIRCULAR ONE?

There are a multitude of different bottlenecks within the Lidl's current Specification. The roof was chosen as an example to show the possibilities and impact of the circular approach. This also relates to the main question for this chapter. Before redesigns can be made, an examination needs to be done on the roof system as a whole. This gives an overview on the actual Disassembly Potential and the total Material Circularity Indicator. In the previous chapter the loose codes in the Specification are analysed. This analysis already gives an overview on the application of different materials and elements. The combination which eventually makes up the main roof function can only be examined for the whole system. This will show the main issues with the roof as a system. Two redesigns will be proposed for this chapter. The first redesign is the technical redesign, which will stay as close to the original design as possible. This will show the Lidl which changes have to be made to the current structure to become circular. The second design will be the green redesign, which will change many technical materials towards biological ones, where economically possible.

6.1. Current situation



Fig. 52: Lidl's current design (source: Lidl standard design)

Before choices can be made on the redesign, the original design has to be thoroughly examined. The roof design is build up from multiple chapters within the Specification, along with a few detail drawings and the general build-up of the load-bearing construction drawings. The roof itself can be classed under four of the layers described in Steward Brands book (Brand, 1994). These four layers can be seen with the following functions:

Structure: With the Load-bearing functions.

Skin: Which contains the functions: insulating, water tight, air tight, load-bearing for subsystems. It also has the optional functions described as: skylights, water retention and energy creation.

Service: The roof is there to assemble the technical infrastructure of: cables, piping supporting technical systems.

Space: This is achieved through the final layer, the dropped ceiling, this allows changes to be made to the space inside and the services.

The construction used to fulfil these functions can be found under a multitude of chapters and codes within the Specification of the Lidl. These provide the best insight in the build-up of the layers. This following part will be in Dutch, these are direct citations from the Lidl's Specification (LIDL, 2017):.

Structure:

Specification

- 25 METALEN DRAAGCONSTRUCTIES
- 25.02 Staalconstructiewerk
- 25.03 Tekeningen en berekeningen

Drawings

- FIL_C01
- FIL_C03

Skin:

- 25.04 Staaldak

33 DAKBEDEKKINGEN

- 33.02 Tekeningen en berekeningen
- 33.03 Voorbehandeling ondergrond, baanvormige dakbedekking
- 33.04 Dak isolatie
- 33.05 Kunststof dakbedekkingssysteem, mechanisch bevestigd
- 33.06 Aan te brengen voorzieningen
- 33.07 Noodoverstorten
- 33.08 Valbeveiliging
- 33.09 Dakverhardingen
- 33.10 Doorvoeringen

37 ISOLATIE

- 37.02 Glaswol
- 37.03 Hardschuim
- 37.04 Steenwol
- 37.05 PIR(na isolatie)
- 37.06 Cannelure vulling

Service:

- 44 PLAFOND- EN WANDSYSTEMEN

- 44.02 Rasterplafonds

- 52 WATERINSTALLATIES

- 52.01 Algemeen

Space:

- 44.02 Rasterplafonds
- 44.03 Panelenplafonds
- 44.04 Gipsplaatplafonds
- 44.05 In het werk af te werken systeemwanden

For the details:

- DAK_D03
- DAK_D06
- DAK_D07
- DAK_D08
- DAK_D09
- DAK_D11
- DAK_D12a
- DAK_D12b

Each of the above described codes relate to a part of the roofing system. With the combination of these code's, and drawings an extensive analysis and redesign can be done on the roof. In the appendix the full codes and drawings can be found, here a few excerpts are addressed. Starting with the longest lasting layer, the Structure, down to the shortest lasting layer, the Space plan. The picture below shows the layers of the Skin, which consists out of four layers throughout the roof design. The actual construction principles differ through the roof structure, two typologies are used, the hexagonal steel plates between the load-bearing structure(detail DAK_D01) or on top of the load-bearing structure(detail DAK_D10).

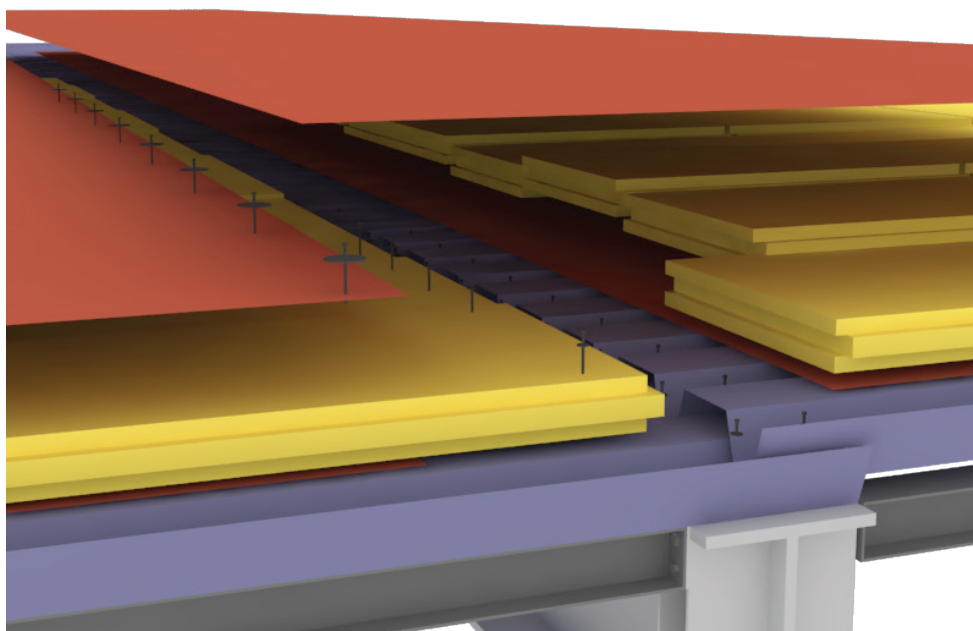


Fig. 53: The load-bearing principles of the roof structure: first typology, on top of the load-bearing structure(source: own image)

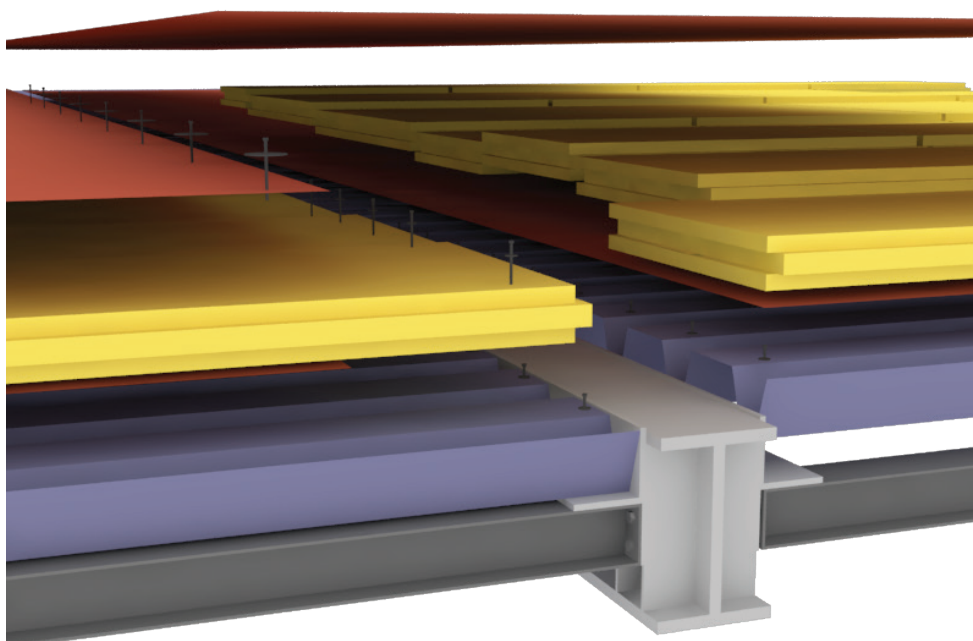


Fig. 54: The load-bearing principles of the roof structure: first typology, besides the load-bearing structure(source: own image)

On top of these hexagonal plates a vapour barrier is positioned, the vapour barriers are adhered to each other with tape. On top of the vapour barrier lies the PIR insulation. The PIR plates are connected by the geometry of their edge, they have indents and extensions which fit together like a puzzle to create an airtight layer. The final layer is the roofing membrane. This membrane covers the PIR panels and makes the structure water tight. Where two membranes overlap they are mechanically fastened to the steel plates. This mechanical fastener goes through the PIR and Vapour barrier to fasten those too. The top roofing membrane is then adhered to the bottom layer. The whole structure is hidden, in almost all supermarkets, behind a drop down ceiling. This layer also hides the cables and pipes used for the service layer.

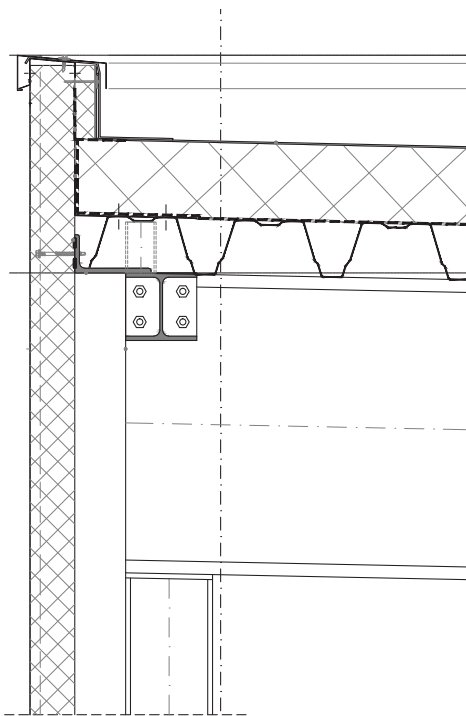


Fig. 55: The load-bearing principles of the roof structure: first typology, on top of the load-bearing structure (source: Lidl DAK_D10)

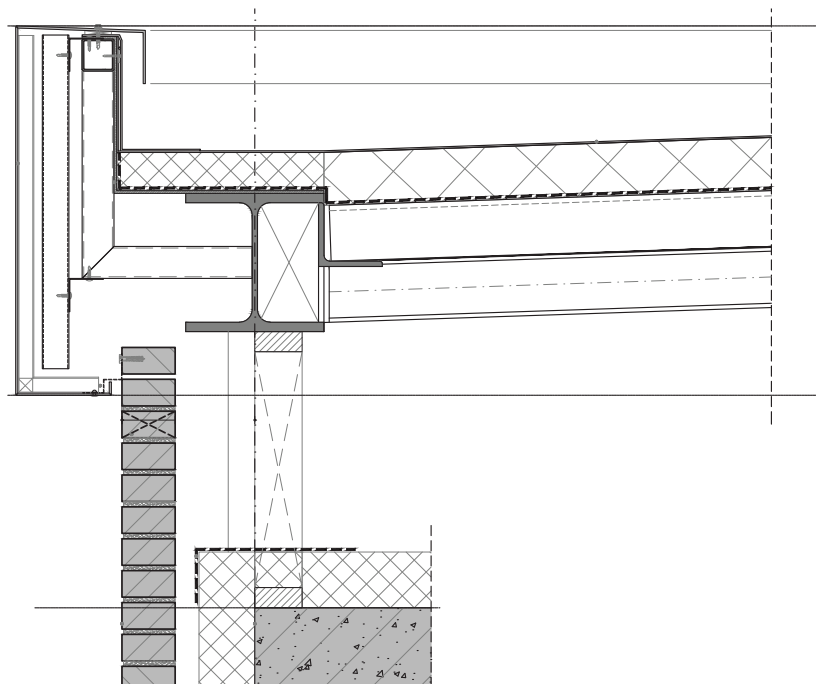


Fig. 56: The load-bearing principles of the roof structure: first typology, besides the load-bearing structure (source: Lidl DAK_D01)

Through these drop ceilings, and the other finishing layers, all supermarkets are made with a generic feel on the inside. Each supermarket uses exactly the same, materials and elements. It also provides us with a question that will be leading for the redesigns: If you want the inside to look generic, why isn't the structure generic? With the knowledge of all the materials examined in the Specification, an analysis for the Material Circularity Indicator and the Disassembly Potential can be done.



Fig. 57: Drop ceiling, Lidl multatuliweg Delft (source: own image)

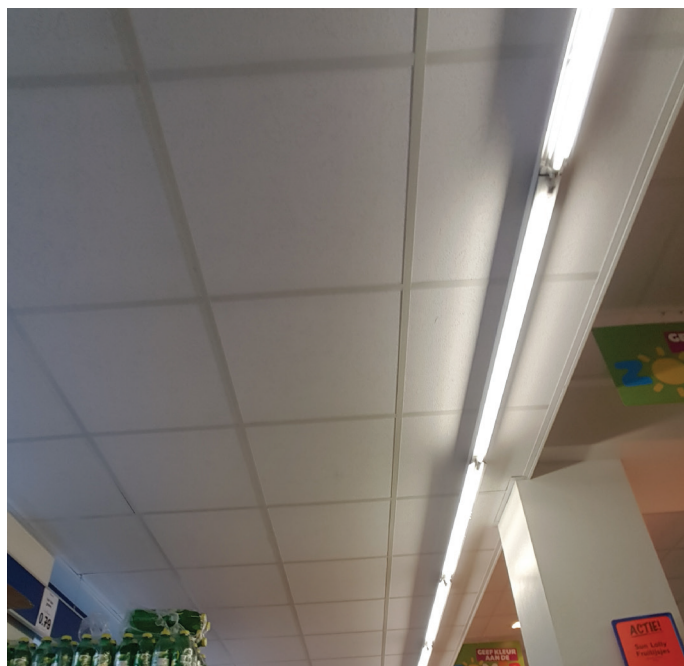


Fig. 58: Drop ceiling, Lidl Doctor H.J. van Mooklaan Rijswijk (source: own image)



Fig. 59: Drop ceiling, Lidl Wesselsstraat Den Haag (source: own image)



Fig. 60: Drop ceiling, Mercuriusweg Delft (source: own image)

6.1.1. Material Circularity Indicator

As described in the paragraph before, the original design of the roof can be found under many codes in the Specification. The codes which contain the descriptions about the materials used, can mostly found under **25 (Metalen draagconstructies)** and **33 (Dakbedekkingen)**. These chapters give the following descriptions for the materials used:

- 25.01.09 Oppervlaktebehandeling:
- staal buiten:
 - . zichtwerk, inclusief spouw; thermisch verzinkt overeenkomstig NEN-EN-ISO 1461 en voorzien een polyester poedercoating (Duplex volgens NEN 5254:2003); droge laagdikte min. 90µm, in de spouw 120µm; t.p.v. de kustgebieden de zinklaag min. 85µm (corrosieklasse C4 volgens ISO 12944); tenzij na drukkkelijk anders vermeld.
 - . niet zichtwerk, inclusief kruipruimte: thermisch verzinkt overeenkomstig NEN-EN-ISO 1461.
 - staal binnen:
 - . plaatstaal: gecoat plaatstaal uitvoeren in sendzimir verzinkt staal conform NEN-EN 10346.
 - . profielstaal binnen dat niet nader wordt voorzien van een coating: thermisch verzinkt overeenkomstig NEN-EN-ISO 1461.
 - . profielstaal binnen in vochtige omstandigheden, niet zichtwerk: thermisch verzinkt overeenkomstig NEN-EN-ISO 1461, tenzij nadrukkelijk anders vermeld.
 - . profielstaal binnen in vochtige omstandigheden, zichtwerk: thermisch verzinkt overeenkomstig NEN-EN-ISO 1461, en voorzien van een polyester poedercoating; droge laagdikte min. 60 µm.
 - . overige profielstaal binnen, niet zichtwerk: reinigen door stralen, straalreinheid Sa 2½ ISO-8501, voorzien van een zinkrijke primer; droge laagdikte min. 70µm.
 - . overige profielstaal binnen, zichtwerk: reinigen door stralen, straalreinheid Sa 2½ ISO-8501, voor zien van een epoxy polyester primer van 70µm, en een epoxy polyester poedercoating; droge laagdikte min. 60µm.
 - alle mechanische bewerkingen moeten voor het verzinken resp. meniën geschieden.

The steel used within the beams for the load-bearing structure and the steel used for the roofing plates are both galvanized. This protects the steel from rust. The steel plates and beams also get a powder coating, on an epoxy-polyester basis. This lengthens their life span, makes them easier to clean and more damage resistant (Coating.nl, n.d.). The plates do get a further description, within the Specification, this is mainly on their expected size and materialization and profile. The materials used for the rest of the roof are described under the code 25.04 (Staaldak). The plates are specified as:

- 25.04.11 **Staaldak**
Sendzimir verzinkte profielplaten, minimaal 25 micron zinklaagdikte per zijde. Aan de onderzijde voorzien van Colorcoat PE25/Polyester, kleur conform kleurenstaat. Naschilderen niet toegestaan. Afmeting en dikte volgens tekening(en).
Lengterichting van de profielplaten: lengterichting staalplaten = lengterichting verkoopruimte.
De platen dienen de kipstabiliteit van de stalen liggers te verzorgen. *De kipstabiliteitsberekening dient te worden uitgevoerd door de aannemer/staalbouwer en ter controle aan Lid1 te worden aangeboden.*
- Stalen dakplaten aan de kopse zijde voorzien van cannelure vulling conform 37.06.
- Alternatief bij luifelconstructies:
Sendzimir verzinkte profielplaten (ongecoat), minimaal 25 micron zinklaagdikte per zijde. Afmeting volgens tekening(en).

This profiling of the steel plate isn't surprising, the profile in the plates ensures they can remain thin and light weight, but have enough height to support remaining layers and variable forces on the roof.

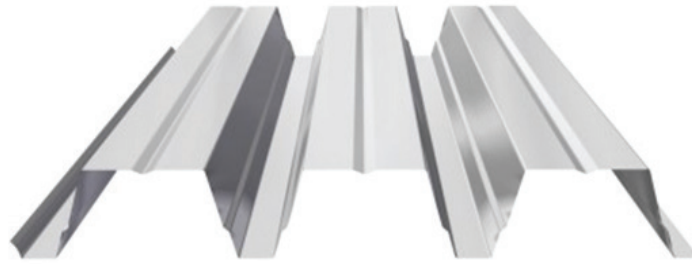


Fig. 61: *Sendzimer profielplaat*(Hardeman, n.d.)

These two together provide the load-bearing structure, the beams on the structural level, the plates on the Skin level.

On top of this the roofing itself is situated, this roofing is described under code **33 (Dakbedekking)**. The roofing consist out of three layers. The first layer is the vapour barrier, Low Density PolyEthene foil(LD-PE). This layer is described in the following Specification paragraph. This shows the exact brand which should be used. As can be seen when examining the material, the foil is a very lightweight material. With only a thickness of 0.4 mm the foil has barely any influence on the total weight of the roof.

- 33.03.02 Naadafwerking/dampremmende laag
Dampremmende laag.
Materiaal:
- LDPE folie.
Bevestiging:
- Losliggend, overlap (mm): 100;
- Overlappen getaped met dubbelzijdig tape;
- Aan alle randen en langs opgaand werk ruim min. 20 mm boven het nivo van de isolatie doorzetten.
Polyetheenfolie
Fabrikaat: Sika AG;
Materiaal: High Density Polyetheen (HDPE);
Type: Samavap 1000 of 2000;
Afmetingen:

On top of the foil a layer of PIR plates is placed. These PIR plates are used to achieve the demanded Thermal Resistance of $6.0[m^2 \cdot K/W]$. The fire class for the element is, according to the European fire safety scale, a 'B'. This means the material is difficult to combust and won't fuel the fire(Rockwool, 2018). The panels are connected together by dents and grooves, this ensures the airtight nature of the roof and extra overlap improves the insulation.



Fig. 62: PIR insulation plate, with geometric connections (Isolatie-online.be, n.d.)

33.04 Dak isolatie

Detail:	Alle DAK detailleringen
---------	---

33.04.01	Type	PIR-isolatie, aan te brengen conform voorschrift leverancier, warmteweerstand conform 37.01.01.
	Bevestigingsmethode:	Mechanisch bevestigd middels parkers met ronde drukverdeelplaatjes, om-en-om in de bovenzijde van de cannelure, zodanig dat er een ruitenpatroon ontstaat. Zie detaillering. Parkers mogen maximaal 30mm door de dakplaat heen steken. Dampremmende laag – isolatie - dakbedekking dienen conform voorschriften leverancier dakbedekking te worden aangebracht met behoud van alle garantietermijnen; voor bevestiging zie dakbedekking, art. 33.05.01.
	Brandgedrag:	Euroklasse B.
	Kanten:	Vierzijdig tand- en groef; naden strak tegen elkaar; open naden en aansluitingen volzeten met PUR-schuim.
	Legpatroon:	Naden-versprengen- Halfsteens verband.
	Cachering:	Tweezijdig voorzien van een meerlaagse aluminium folie.

PIR isolatie leveren onder KOMO-attest-met-productcertificaat.

- Dakisolatie van platte daken (daar waar op tekening afschotisolatie aangegeven staat deze toepassen);
- Dakisolatie van hellende daken (alternatief);
- [Opvulling van de dakgoot van het hellende dak;](#)
- [Aansluitingen gevel en dak, daar waar de dakbedekking doorgaat over de gevel.](#)

The third layer is also the last layer, it's the roofing membrane. The membrane is on a TPO basis, the product described within the Specification is the Sarnafill TS 77-20 roofing membrane. It is a product made by Sika. As described within the chapter on the analysis of the Specification, the membrane is, in theory, fully recyclable. The adhesives however prevent complete recycling. The adhesives prevent more than 15% of the roof to be incinerated, as the membrane has been contaminated by it.

33.05 Kunststof dakbedekkingstelsel, mechanisch bevestigd

33.05.01

Dakbaan:

- Overlap (mm): minimaal 120;
- Naden gelast d.m.v. hete lucht met lasautomaat.

Mechanische bevestiging

- aantal en positie volgens berekening aannemer, conform NEN-EN 1990 en SBR 239.
- bevestiging d.m.v. ~~Sarnafil SB-schroeven met Sarnafil KTL Sarnafast SFT 50 x L ronde tule + SBF 6,0 x L carbon coated bevestigiger ovale drukverdeelplaatjes~~. Schroeven mogen maximaal 30mm door de dakplaat heen steken. Drukverdeelplaatjes geheel verdekt in de overlap verwerken.
- kinnen mechanisch bevestigen met Sarnabar 6/15 + krachtend verdelend lassnoer FPO 4 mm.

33.05.02

Kunststof dakbaan

Fabriek: Sika AG.

Type: Sarnafil TS 77-20 (TG 66-20 voor de randen e.d.)

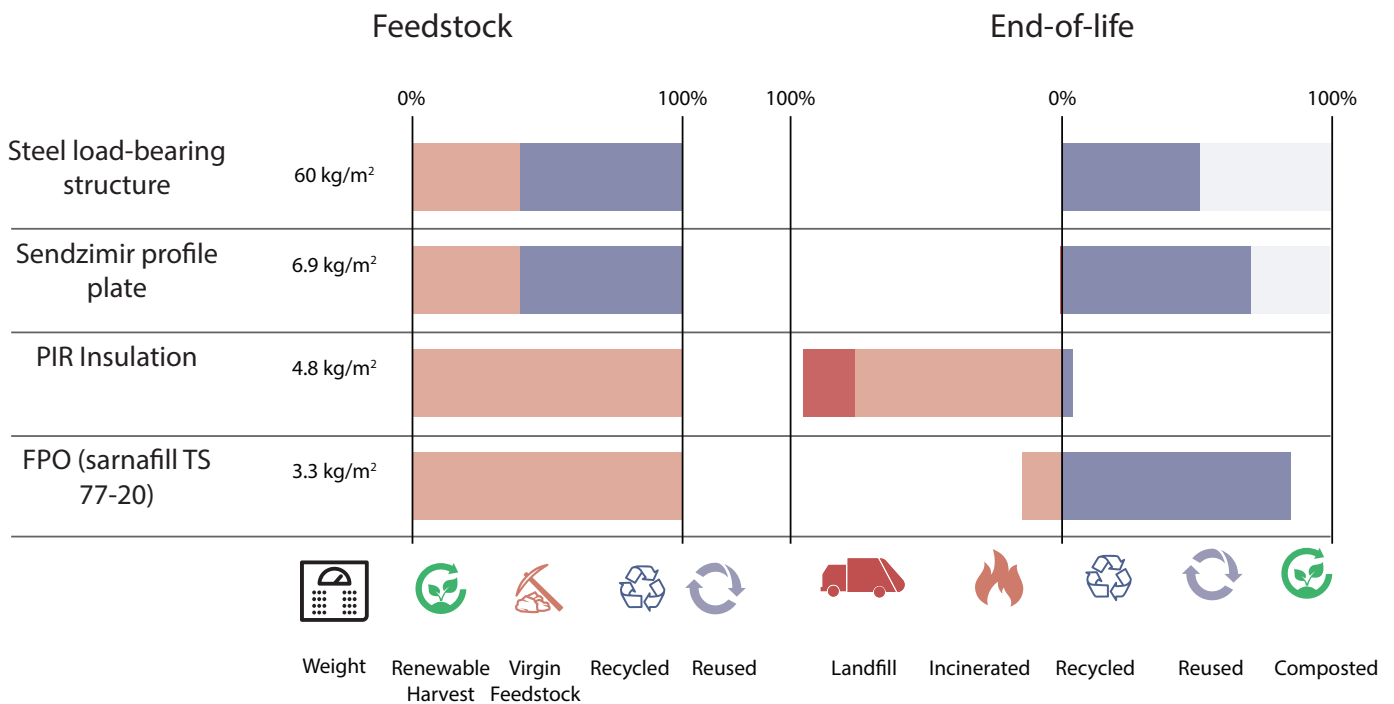
Duurzaamheidscentrificering: **DUBOkeur**;

Kleur: Conform afwerklijst.

Materiaal: Kunststof / FPO-dakbedekking (PVC-vrij).

- Dikte min. (mm): 2.0;
 - Dakmembraam **polyester weefsel en glasvezel versterkt**;
- Begaanbaarheid (BRL1511/01-93): Klasse R3.

The MCI's of the materials were all examined in chapter 5. From this chapter all the values are taken to be examined further for the Material Circularity Indicator of the whole system. The only material with a recycling efficiency lower than 100% is the PIR insulation, which has a efficiency of 0%.



For the MCI it's important to make the choice on which parts you want to compare. The difference between the calculations with and without load-bearing structure show huge differences. This can be seen in table 1 and 2. The load-bearing structure has a high circularity potential, as all parts can potentially be reused or recycled. The steel industry already uses 50% of scrap in their new steel providing high circularity. Because of this only the Skin system is examined, as it's also got the highest change ratio. These factors give us the following results:

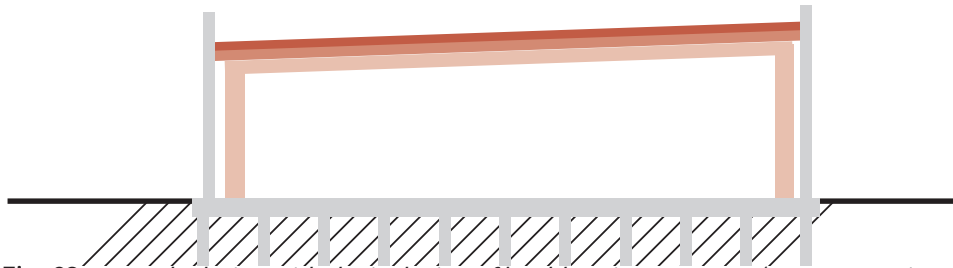


Fig. 63: MCI calculation with the inclusion of load-bearing structure (source: own image)

Step1: Calculate Virgin Feedstock

Material	M(x) (kg)	F _R	F _U	V (kg)
Steel Load-Bearing structure	60	0.6	0	24
Steel Hexagon plate	6.9	0.6	0	2.76
Pir Insulation	4.8	0	0	4.8
FPO Roofing	3.2	0	0	3.2
Total				

Step2: Calculate Unrecoverable Waste

Material	M(x) (kg)	C _R	C _U	W ₀ (kg)	E _C	W _C (kg)	E _F	F _R	W _F (kg)	W (kg)
Steel Load-Bearing structure	60	0.51	0.49	0	1	0	1	0.6	0	0
Steel Hexagon plate	6.9	0.7	0.29	0.069	1	0	1	0.6	0	0.069
Pir Insulation	4.8	0.041	0	4.6032	0	0.1968	1	0	0.1968	4.8
FPO Roofing	3.2	0.85	0	0.48	1	0	1	0	0	0.48
Total										

Step3: Calculate Linear Flow Index

Material	M(x) (kg)	V	W	W _F	W _C	LFI
Steel Load-Bearing structure	60	24	0	0	0	0.2
Steel Hexagon plate	6.9	2.76	0.069	0	0	0.205
Pir Insulation	4.8	4.8	4.8	0.1968	0.1968	1
FPO	3.2	3.2	0.48	0	0	0.575
Total						0.096206

Step4: Calculate Utility Factor

Material	L	L _{AV}	U	U _{AV}	X	F
Steel Load-Bearing structure	75	75	1	1	1	0.9
Steel Hexagon plate	20	75	1	1	0.266667	3.375
Pir Insulation	20	75	1	1	0.266667	3.375
FPO	20	30	1	1	0.666667	1.35
Total						

Step4: Calculate MCI

Material	LFI	F	MCI* _p
Steel Load-Bearing structure	0.2	0.9	0.82
Steel Hexagon plate	0.205	3.375	0.308125
Pir Insulation	1	3.375	0
FPO	0.575	1.35	0.22375
Total	0.248865		0.694821

Table 1 : MCI calculation with the inclusion of load-bearing structure (source: own table)

The difference between the calculation with and without the load-bearing structure show huge differences. If the load-bearing structure is taken along in the calculation the LFI and MCI achieve a far more circular result. As the weight and circularity score highly influences the score through its weight.

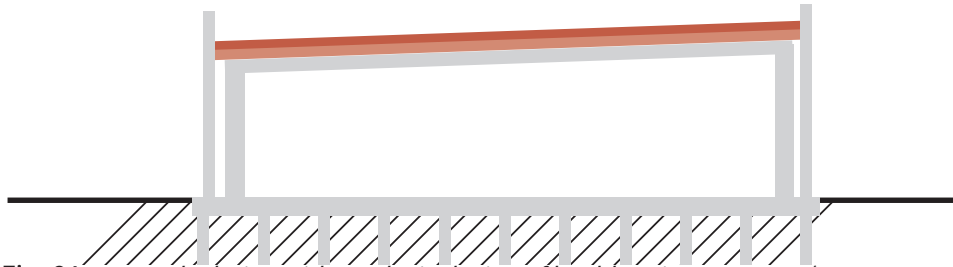


Fig. 64 : MCI calculation without the inclusion of load-bearing structure (source: own image)

Step1: Calculate Virgin Feedstock

Material	M(x) (kg)	F _R	F _U	V (kg)
Steel Hexagon plate	6.9	0.6	0	2.76
Vapour Barrier	0.2	0.6	0	0.08
Pir Insulation	4.8	0	0	4.8
FPO Roofing	3.2	0	0	3.2

Step2: Calculate Unrecoverable Waste

Material	M(x) (kg)	C _R	C _U	W ₀ (kg)	E _C	W _C (kg)	E _F	F _R	W _F (kg)	W (kg)
Steel Hexagon plate	6.9	0.7	0.29	0.069	1	0	1	0.6	0	0.069
Vapour Barrier	0.2	0.05	0	0.19	1	0	1	0	0	0.19
Pir Insulation	4.8	0.041	0	4.6032	0	0.1968	1	0	0.1968	4.8
FPO Roofing	3.2	0.85	0	0.48	1	0	1	0	0	0.48
										5.54

Step3: Calculate Linear Flow Index

Material	M(x) (kg)	V	W	W _F	W _C	LFI
Steel Hexagon plate	6.9	2.76	0.069	0	0	0.205
Vapour Barrier	0.2	0.08	0.19	0	0	0.675
Pir Insulation	4.8	4.8	4.8	0.1968	0.1968	1
FPO	3.2	3.2	0.48	0	0	0.575

Step4: Calculate Utility Factor

Material	L	L _{AV}	U	U _{AV}	X	F
Steel Hexagon plate	20	75	1	1	0.266667	3.375
Vapour Barrier	20	75	1	1	0.266667	3.375
Pir Insulation	20	75	1	1	0.266667	3.375
FPO	20	30	1	1	0.666667	1.35

Step4: Calculate MCI

Material	LFI	F	MCI* _p
Steel Hexagon plate	0.205	3.375	0.308125
Vapour Barrier	0.675	3.375	0
Pir Insulation	1	3.375	0
FPO	0.575	1.35	0.22375
Total	0.54		0.19

Table 2 : MCI calculation without the inclusion of load-bearing structure (source: own table)

The complete roofing system receives a Linear Flow Index score of 0.45, the final Material Circularity Indicator receives a score of 0.16. These examples show why it is important to make the right choices, in which materials you do and do not include. The materials used aren't fully circular, but they are hampered further by their use factor. The figure below shows the materials which make up the roof system. There is potential to extract more value out of the materials currently employed by reusing. The current system isn't made for reuse. All materials used within the roof system, except for the steel will be demolished instead of disassembled at their end of life. The FPO membrane is fully recyclable, the supplier is also willing to take it back as long as the layers are clean. The same goes for the Vapour barrier. If the layers can't be disassembled they up incinerated, to regain the energy from the material(NIBE, 2018d). PIR has the unfortunate properties that recycling is very expensive, because of this reason it usually ends up incinerated(NIBE, 2018e).

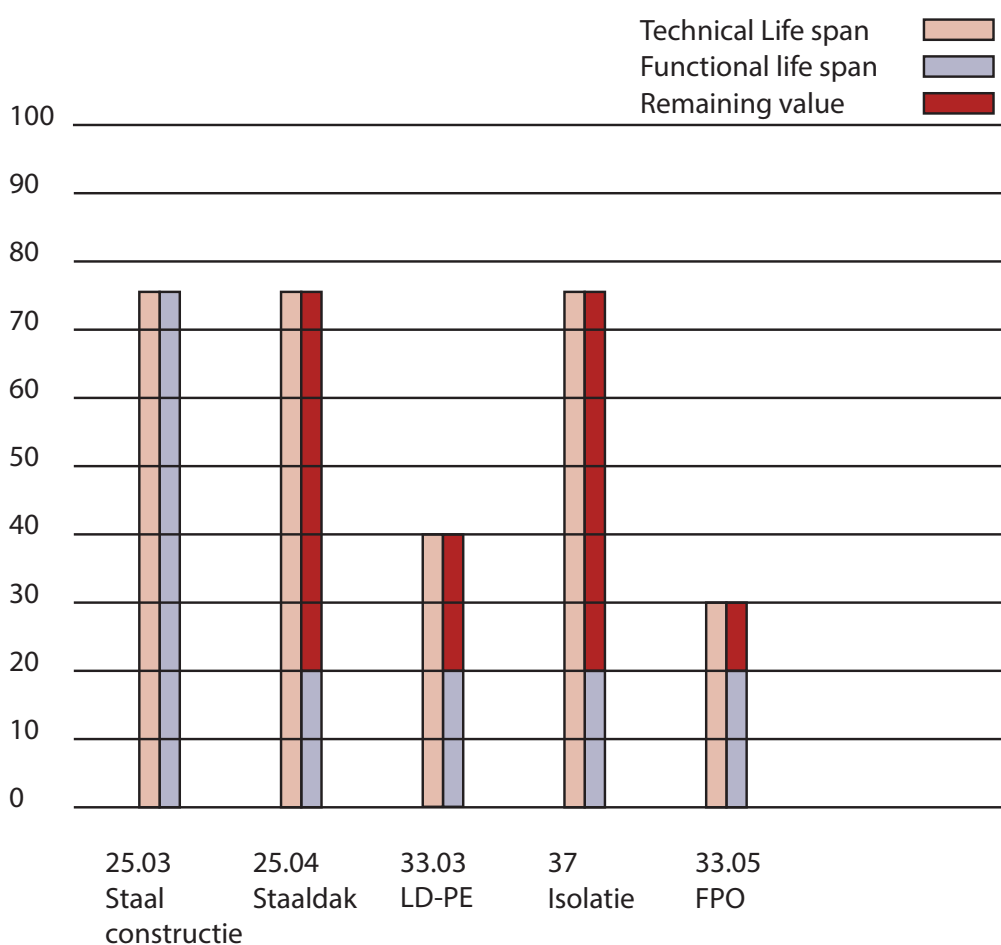


Fig. 65 : Life cycle analysis of the roof structure. Technical life, compared to Functional life in years. (source: own image)

6.1.2. Disassembly Potential

With all the details and the Specification, the whole roof can be examined on its disassembly potential as well. It has a few interesting characteristics which are prevalent throughout the design. Two typologies can be distinguished within the roof system. The roof plates are either located between the Load-bearing structure or on top of it. These two different layers require slightly different assemblies. The plates connected to the top of the beam can just be laid down and screwed on top of the beams. The plates laid between the load-bearing structure require an extra profile, this profile is welded to the HEA beam, the beam becomes more specialized through this addition and more difficult to reuse. Besides this small structural difference, the skin layer is constructed with the same layers throughout the whole structure. The Disassembly Potential for the whole roof can be examined and be determined as applying to almost all of the roof structure. The order in which the roof system will be assessed is the same as the order in which the DP was constructed in chapter 3. First the Functional Decomposition, followed by the Systematisation. The third is the Base Element, with after that as fourth the Life-cycle Coordination. Fifth is the Relational Patterns, sixth the Assembly and as seventh the Geometry. Last but not least, as eight, are the Connections.

Functional Decomposition(FD):

The current roofing structure contains six functions, the addition for two more functions can be made on top of the current structure. The functions for the roof are: water tight, air tight, fire resistance, insulating (RC of at least 6.0), technical infrastructure (cables and piping) and load-bearing. The two that can be added are the sedum roof and a PV system. In the roofing system all the layers preform their own functions, there are no layers which preform double duty. Problems arise when additions to the systems on the roof need to be made. If windows or PV will be installed, the structure needs to be completely rebuild, losing the layers in the process. This results in an interesting contradiction, where its clear which product preforms which function, but they completely depend on each other. This results in a score for the Functional separation (fs) of 1 and Functional dependence (fdp) of 0.1.

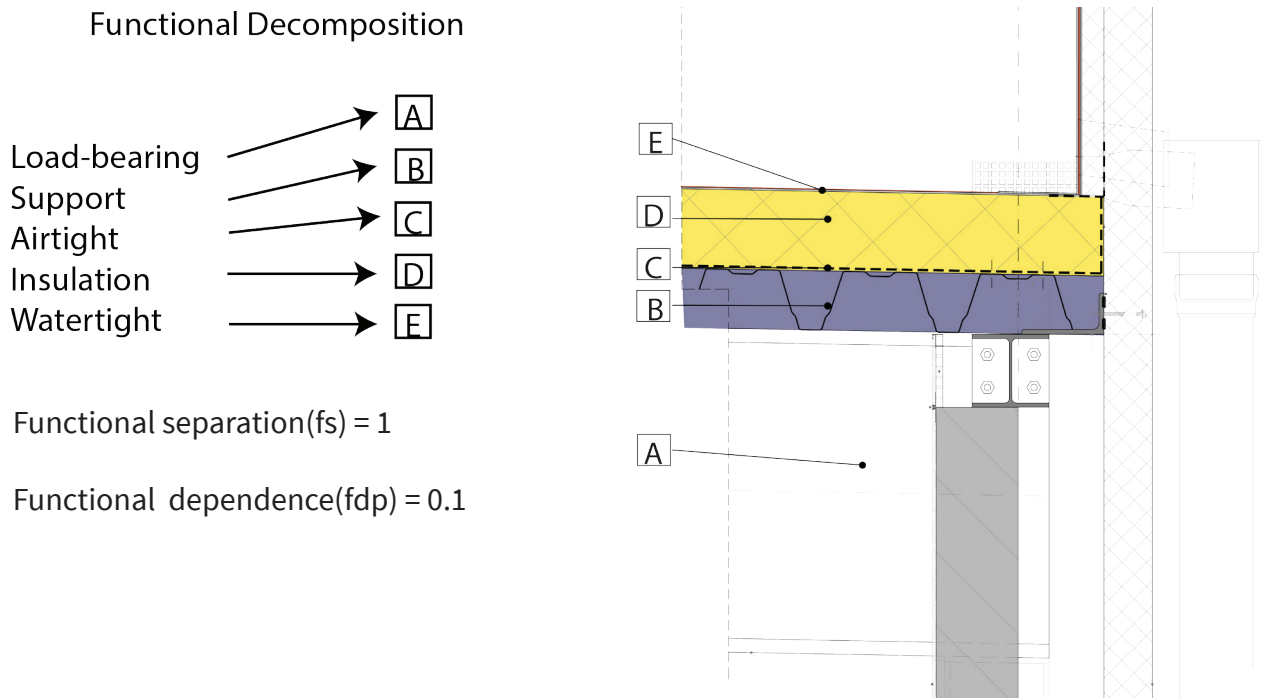


Fig. 66 : Functional Decomposition score(source: own image)

Systematisation(SYS):

The structure makes use of elements only, these elements are all assembled in a layered fashion, making the whole roof a static structure. All major assembly work has to be done on-site. The result is deconstruction work also has to be done on site. Resulting in many handling, increasing labour and making disassembly a costly project. This results in a medium score for the Structure and materials levels, a score of 0.6(st). No clustering happens within the project, each material an function is kept completely separate and only come in contact with each other on the site, for this it receives the lowest score of 0.1(c).



Fig. 68 : FPO roofing , element E (Mapeplan, n.d.)



Fig. 71 : LD-PE vapour barrier(Miofol, n.d.)



Fig. 69 Fig. 58: PIR isolatie plaat, tand en groeff, element D(Isolatie-online.be, n.d.)

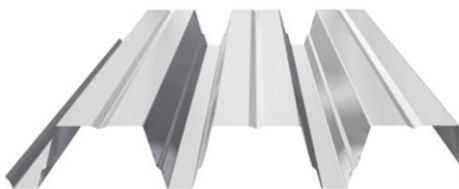
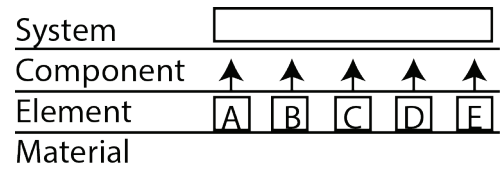


Fig. 70 Fig. 57: Sendzimer profielplaat, Element B (Hardeman, n.d.)



Structure and material levels (st) = 0.6

Clustering(c) = 0.1

Fig. 67 : Systematisation, on site construction (source: own image)

Base Element(BE):

Within the Lidl’s current design there isn’t a Base Element that separates the major functions. All materials are connected directly to each other. The roof structure is connected directly to the major load-bearing structure. You can’t disassemble the roof plates without damaging the connections to the beams. For this the base element receives a score of 0.1(be).

Life-cycle Coordination(LCC):

The materials used by the Lidl all have very long lifespans. All, except for the roof, have a technical lifespan of 75 years. The roofing membrane has an expected life of 30 years. These materials have a slight mismatch between their life cycle length and their functional length. The skin of a structure is generally expected to last 20 years (Brand, 1994). This is also described in the Lidl's Specification, as they expect the roofing membrane to get a warranty of 20 years (LIDL, 2017).

- 33.01.06 Te garanderen onderdelen
 Voor de volgende onderdelen wordt een garantie verlangd die moet gelden vanaf het gereedkomen van het onderdeel tot aan de oplevering van het werk en in aansluiting daarop gedurende de vermelde periode.
 Onderdeel:
 - Het Sarnafil daksysteem;
 - Te garanderen door: de producent van de dakbaan en het dakdekkingsbedrijf;
 - Periode: 20 jaar.
 Garantie:
 - Sika 20 jaar product garantie

This while the products themselves function for far longer than they are functionally employed. The use life-cycle coordination (ulc) ends up with the higher score of 0.8 (ulc). The same goes for the Technical life cycle coordination (tlc), as the material with the shortest life span, the membrane, is situated as the outer most layer of the structure. This position allows the layer to be changed every 20 years when needed. The Lidl is slowly introducing sedum and pv roofs over this layer. This makes the layer less accessible. Though the sedum makes the membrane less accessible and more difficult to the replace, it also protects the roofing membrane. The sedum shields the roof from UV, slowing down its degradation, extending the technical service life by 20 years. The points made about the ulc also apply Functional life span to size (s). The elements used within the system are small and light weight. Each can be handled by an individual, without the need for heavy machinery. This results in it in total scoring a 1 (tlc) for the life-cycle coordination.

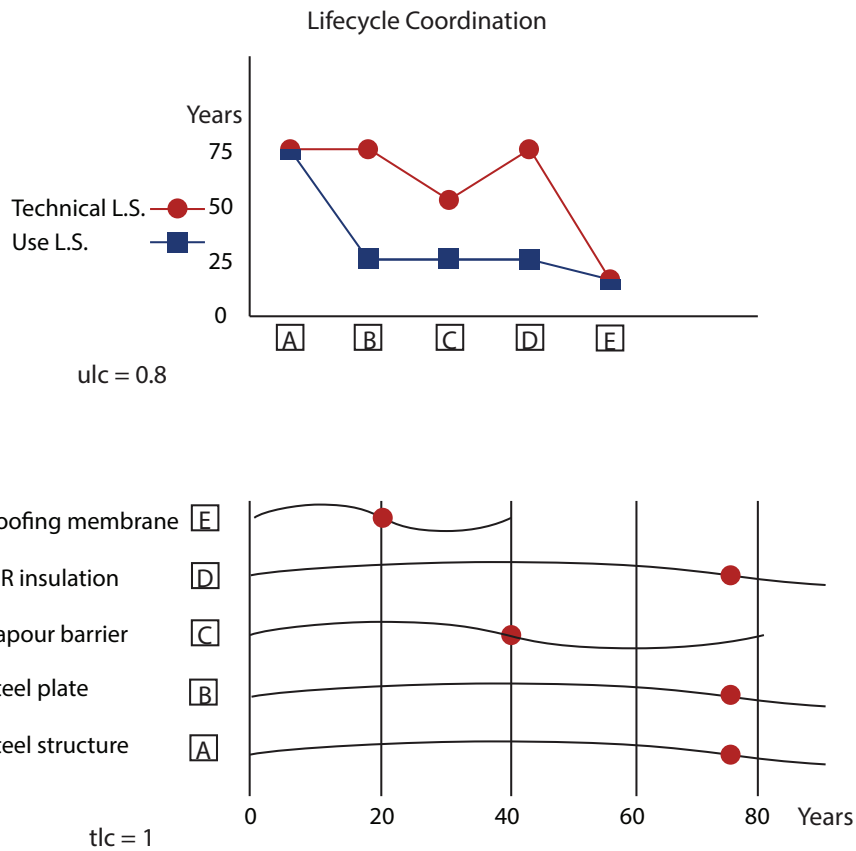
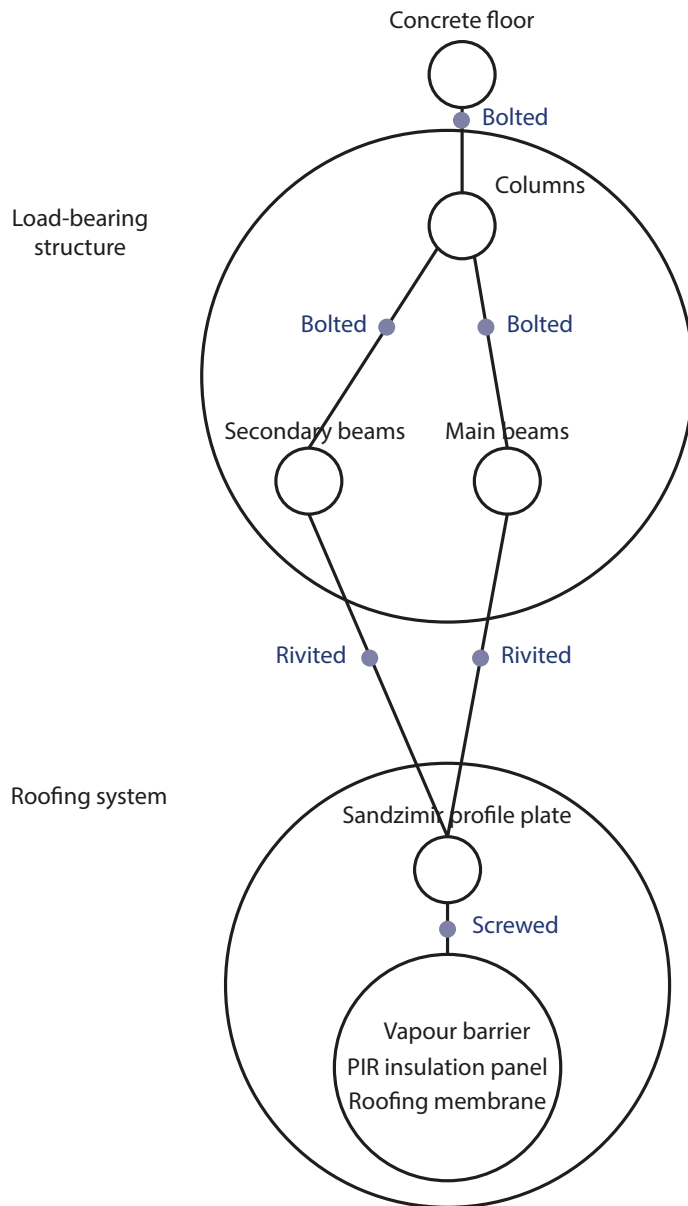


Fig. 72 : Life-cycle Coordination (source: own image)

Relational Patterns(RP):

The way the structure is build-up makes systems rely on each other, thereby mixing functionality between systems. This can also be seen within the relational diagram. The system itself is dependent on each layer
The connection for the vapour barrier, PIR and Roofing membrane is all made with 1 connector, resulting in the layers being stuck to each other. All plates also overlap, resulting in all parts relating to each other, you can't tell with certainty how parts are exact laid on the roof once the roof is closed up. All steel plates are connected with an overlap, the same goes for the vapour barrier and the PIR. This results in horizontal connections between building elements. This results in a score of 0.6.(rp)

Relational paterns



rp = 0.6

Fig. 73 : Relational Patterns in the Lidl's roof (source: own image)

Assembly(A):

The assembly of the structure is completely sequential. Every layer is laid on top of another layer. There is no way to disassemble defect parts. The only way to interfere is to destroy the surrounding parts. The plates are installed with an overlap, on top of that is the vapour barrier. The PIR is installed on top of that with a geometry that fits the pieces together like a jigsaw puzzle. Then the whole structure is encapsulated with a membrane which is also the last layer and connects all parts together. The design shows that the construction can only be done, in a completely sequential manner. This sequential assembly results in a score of 0.1 (ad).

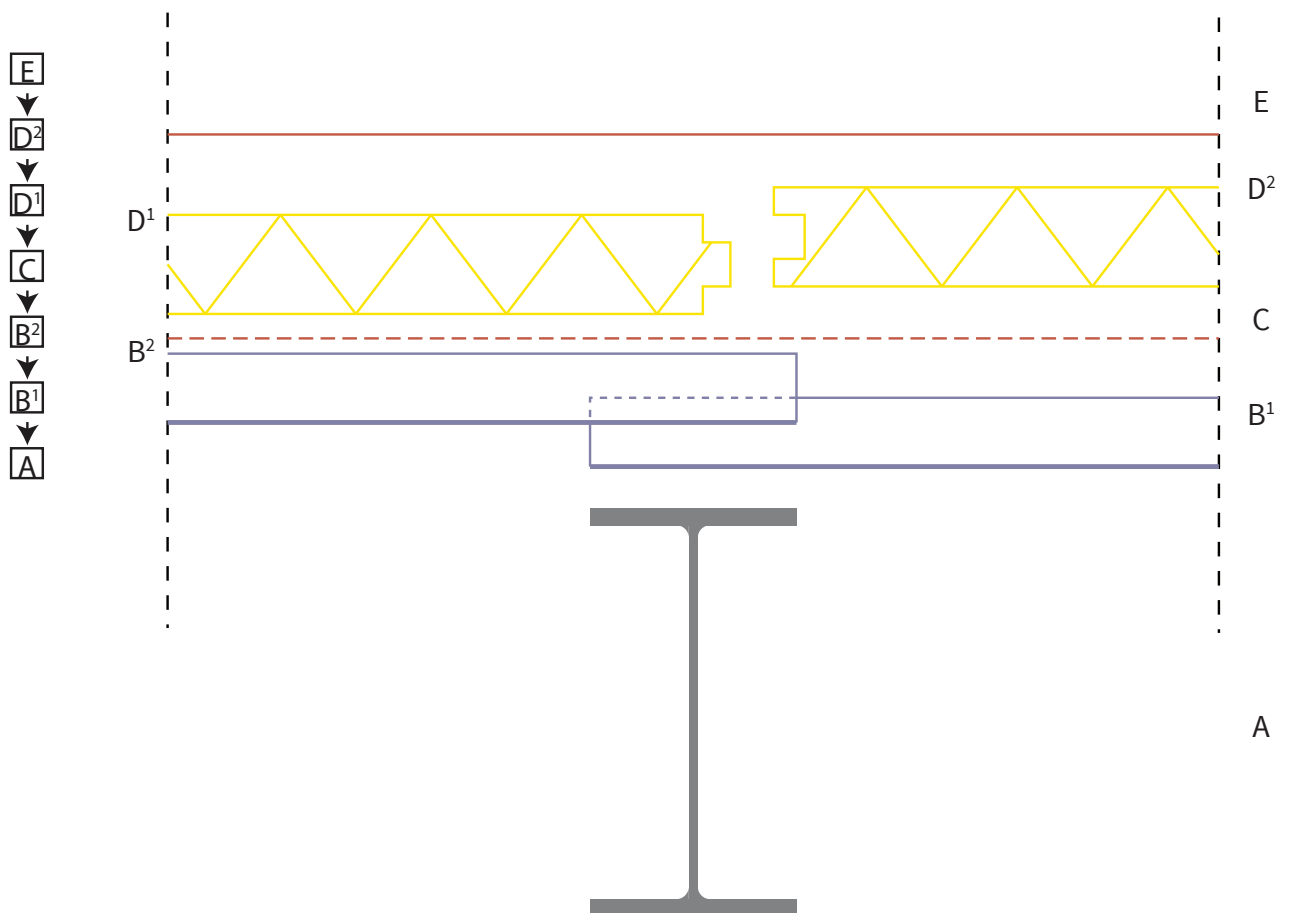
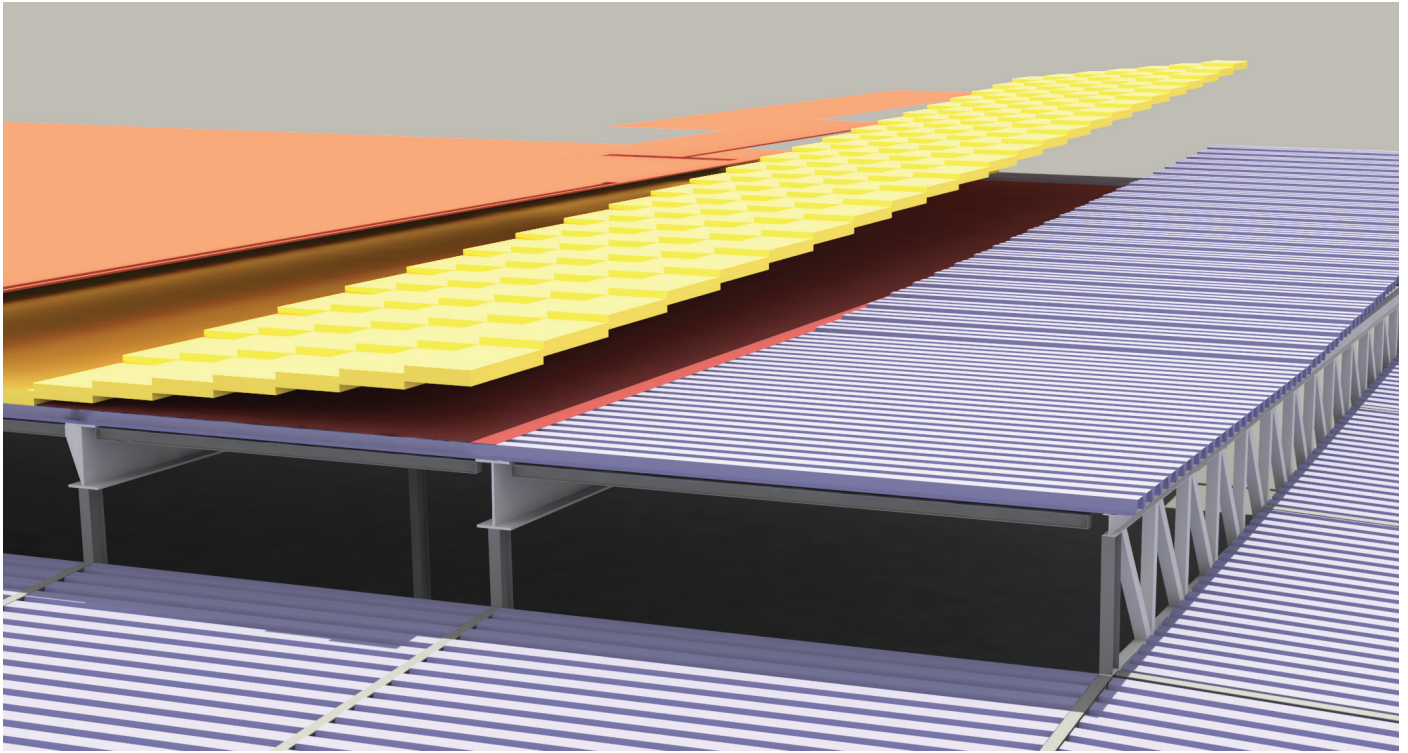


Fig. 74 : Assembly Direction, layered roof structure (source: own image)

Geometry(G):

The same reasons which make the structural assembly sequential, are mostly devised by the product edge. The structure overlaps on multiple levels, making disassembly of one of the middle parts impossible. All layers, except for the PIR layer, result in unsymmetrical overlapping, the PIR layer uses inserts on two sides to be able to connect to the surrounding structure. The geometry required for the edges is all made off-site, as the only part relying on geometry is the PIR. All other materials overlap, which still causes a static assembly. PIR interlocks, prohibiting random disassembly, you have to start disassembling in the corner where the last PIR plate was laid. The result is a lower score, of 0.4(g_e) for the Geometry of the product edge and a 1(s_e) for the standardisation of the edges.

Geometry



$$g_e = 0.4$$

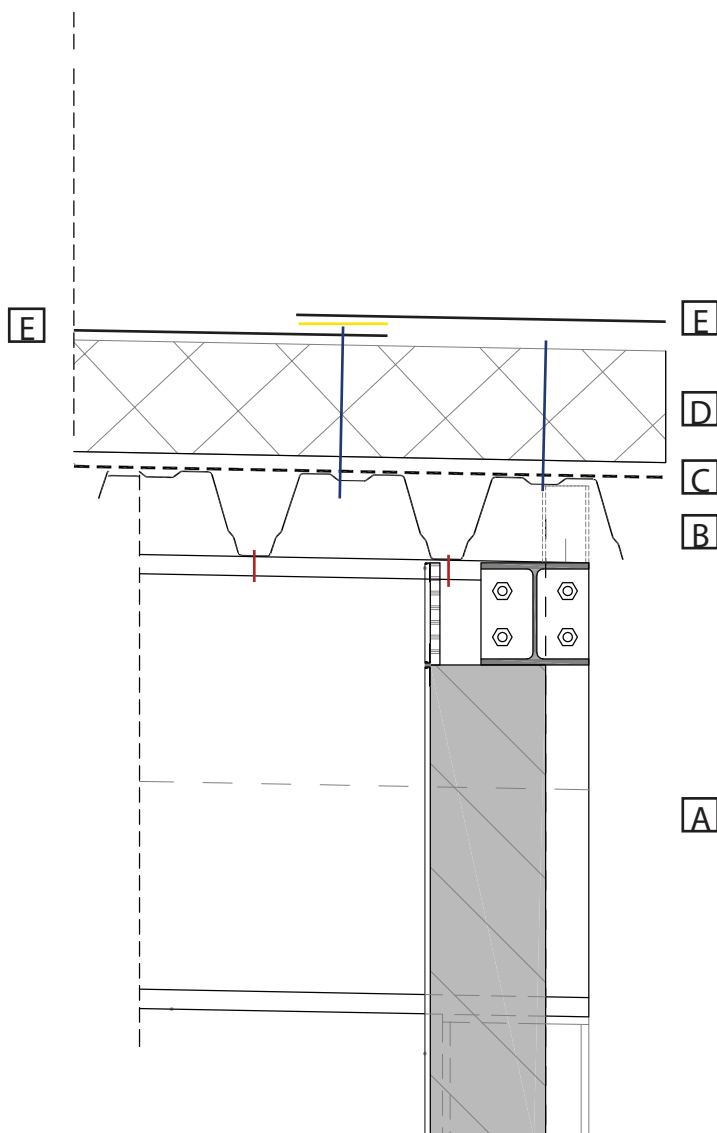
Premade geometry

$$s_e = 1$$

Connections(C):

The connections of the structure rely on mechanical connections, though not all connections are reversible. The plates are riveted to the load-bearing structure. While being a fast method the only way to reverse it is by destroying the connection. All the other layers are connected by just one connections through all the layers. This connection is made through the membrane on to the plate and holds all layers together beneath. The overlap is then closed with adhesives, this results in the mechanical connections being unreachable without destroying the upper membrane. This is also seen in the scores for the connections. The type of connections(tc) Scores low because of this reason. While all connections are made through an indirect mechanical connection, the connections are lost in the upper layer because of the adhesive used. This results in a grade of 0.6 for the total structure. The Accessibility of the fixings also reflects this. While the connections are indirect, they aren't reachable without destroying the upper layer, resulting in total damage for the membrane and possibly even the PIR panels. This results in a score of 0.4 on average for the Accessibility to the fixings (af).

Except for the PIR panels, all other layers are laid loose on top of each other. While being able to remove them requires destroying the top layer, the layers below could be disassembled without many issues. This results in a 0.7 score for the tolerance(t).



Connection		
<div style="display: flex; flex-direction: column; align-items: center;"> <div style="border: 1px solid black; padding: 2px;">A</div> <div style="margin: 2px;">↑</div> <div style="border: 1px solid black; padding: 2px;">B</div> </div>		tc = 0.8 af = 0.4
<div style="display: flex; flex-direction: column; align-items: center;"> <div style="border: 1px solid black; padding: 2px;">B</div> <div style="margin: 2px;">↑</div> <div style="border: 1px solid black; padding: 2px;">C</div> </div>		tc = 0.8 af = 0.4
<div style="display: flex; flex-direction: column; align-items: center;"> <div style="border: 1px solid black; padding: 2px;">B</div> <div style="margin: 2px;">↑</div> <div style="border: 1px solid black; padding: 2px;">D</div> </div>		tc = 0.8 af = 0.4
<div style="display: flex; flex-direction: column; align-items: center;"> <div style="border: 1px solid black; padding: 2px;">D</div> <div style="margin: 2px;">↑</div> <div style="border: 1px solid black; padding: 2px;">E</div> </div>		tc = 0.8 af = 0.4
<div style="display: flex; flex-direction: column; align-items: center;"> <div style="border: 1px solid black; padding: 2px;">E</div> <div style="margin: 2px;">→</div> <div style="border: 1px solid black; padding: 2px;">E</div> </div>		tc = 0.2 af = 0.4

Low Tolerance
t = 0.5

6.1.3. Original Design Results

The inputs themselves already show on which parts there is room for improvement. The combined results give an insight in the overall end-of-use scenario of the total supermarket roof design. With these inputs the outputs for the four levels are created. The results can be seen in the diagrams below. The Transformation Capacity received a score of 0.44. As established in chapter 3 this score shows us that it is likely that 30-70% of the structure will end up landfilled, incinerated or down cycled. This is also reflected by the Material Circularity Indicator.

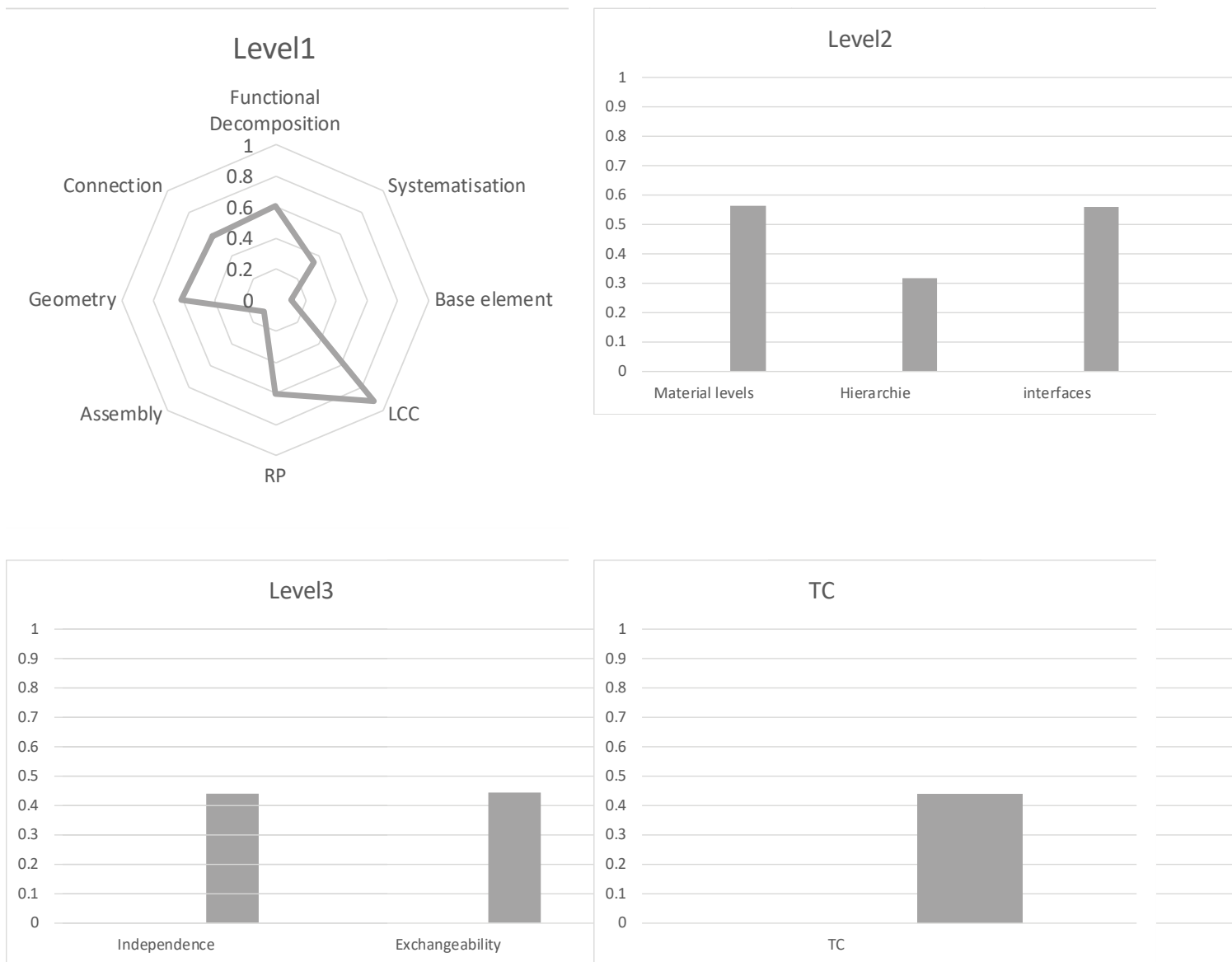


Fig. 75 : Results from the excel model. (source: own image)

As the diagrams show the Lidl can greatly increase many of the facets of their building design. The one point they get a decent score is on the LCC, this is achieved mostly through the use of long lasting materials and ordering the layers on their functional life span. On every other part they score average. On the Base Element and the Assembly there is still much to gain.

6.1.4. Redesign

The first redesign will examine a few options to increase the MCI and DP of the roof that is currently used, try to make the roof fully circular and provide a Transformation Capacity of at least 0.67. Currently there are multiple bottlenecks within the roof design. The steel load-bearing and sub structure have got a decent MCI, the layers above require some tweaking, the material used, the connecting principles or just contracts with the supplier of the material need to be re-examined or redesigned. While both the vapour barrier and the TPO foil have bad Material Circularity Indicator's, in theory they can become fully circular with the right assembly method and contracts with the supplier. The PIR on the other hand is a completely non-circular material. The only choice is to down-cycle the material and incinerate it afterwards. This results in the following steps which have to be taken. The first of these steps is:

- Exchange non-circular materials for a comparable circular materials
- Enable disassembly and re-use in your design.
- Change the Specification where necessary to ensure the circularity.

The second redesign tries to shift the focus of the materials used. The materials used within the Lidl's Specification are all in the technical cycle. This would include the same steps as the first redesign, except the first step would get a different focus:

- Exchange the materials for circular biological ones.
- Allow for disassembly and re-use
- Apply these to the Specification

Roadmap:

As described by Durmisevic there are four levels in a building: the building, the system, the component and the element. Each level represents a combination of functions, down to the element level which is the lowest level that can fulfil a single function. This is the idea which needs to be applied to the design too. The chosen system to redesign, the roof system, defines which functions should be included into the design. As described by the Lidl's Specification and in a conversation with their spokesperson on their expectancy of the building functions, these notions were established.

The functions expected by the Lidl of the roof are:

- Water tight
- Air tight
- PV
- Fire resistant according to standards
- Insulation (RC of at least 6.0)
- Aesthetically pleasing
- Space for services and their infrastructure
- Load-bearing according to standards

Preferable extra functions are:

- Water retention
- Natural Northern lighting

Each of these functions will be represented by an element, a combination of materials. This is the first step within the roadmap, element choice, which is one of the most important steps into the circular design. The choice of material determines the end-of-life scenario (Maccarini & Avellaneda, 2012), no matter how well the structure can be disassembled, if there is no right end-of-life scenario the element will end up as waste. In the previous chapters the principles for the Circular Economy and the methods to measure this have been discussed and applied.

The first step for the element choice is determine the cycle:

1. Biological cycle
2. Technical cycle

The second step, determine the feedstock of your element:

1. Reused elements
2. Recycled feedstock
3. Virgin feedstock

The third step is determine the end-of-life scenarios your element:

1. Reuse
2. Recycle/composting
3. Down-cycling/incineration
4. Landfill

The fourth step is to determine how the layers relate to each other. This is resembled by the Functional Decomposition. This results in three yes or no questions question, each question represents a building level:

- Does a system represent only one of the major building functions(Structure, Skin, Service, Space Plan, Stuff)(Brand, 1994)?
- Does a component only represent the major system functions?
- Does an element only represent an specific function (bearing, finishing, insulating, reflecting, distributing, etc.)?

The fifth step is determining how many different connections are needed for your design, are connections for a function generic?

- The function has a standardized connection throughout the design.
- The function has a multitude of documented connections.
- Connections are made on site.

These first steps cover the questions on the circularity of the materials used, the next step is the Disassembly Potential. For this, the topics from the Disassembly Potential can be applied. The order in which they are addressed is the same as in chapter 3.

6.2. Technical redesign

For the first redesign the material choice will stay close to the original, with minor tweaks to the overall design. The redesign will try to make the building completely circular and increase the Disassembly Potential. For this case the materials will be kept close to the materials originally used in the Lidl design.

Both the change for materials to circular varieties and the improvement of disassembly, can't be examined separately. They depend on each other as some materials simply fulfil functions better than other materials, this also includes the method through which you connect them. There is a multitude of steps that has to be taken before the definitive redesign can be made.

The first step to take however, is to take a look at the current construction diagram of the load-bearing structure, and make it generic. The way this structure is made ensures that two different construction principles are needed for the roof. A multitude of different lengths is used within the structure, this results in 14 different steel profiles and beams within the structure, as can be seen in drawing FIL_CON1, while five or six beams would be sufficient. The first step would be to homogenise the assembly method for the roof structure and with it the dimensions. This allows for standardisation and improves your chances of disassembly and reuse of the beams (Cullen & Drewniok, 2016).

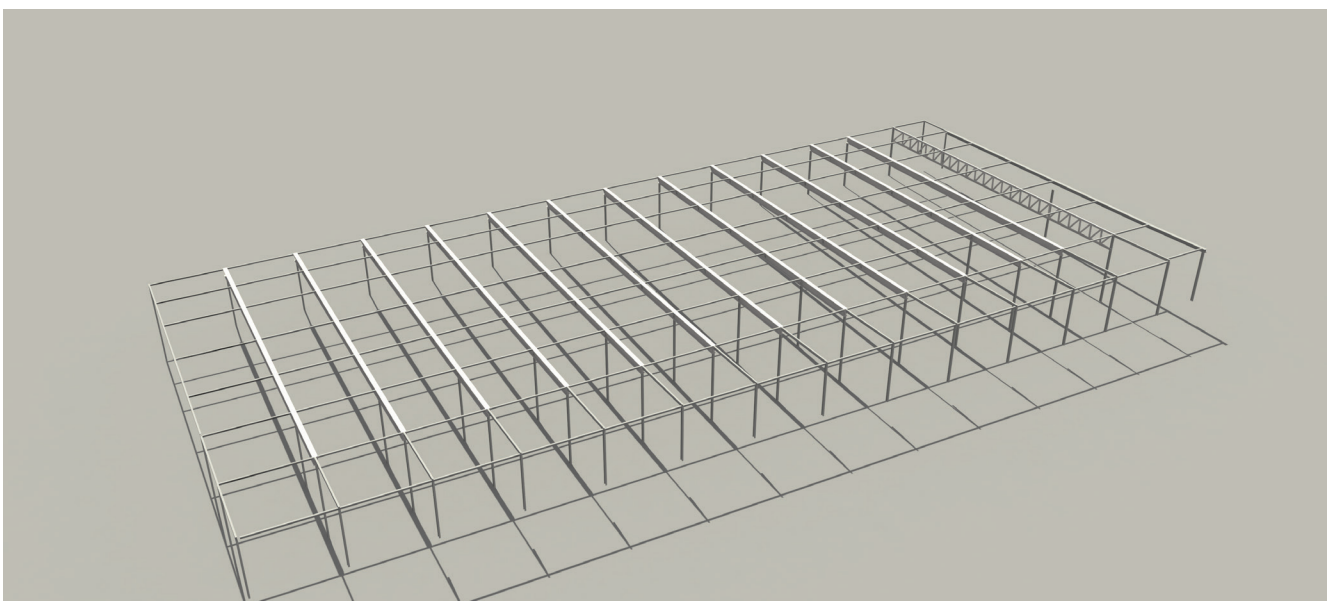
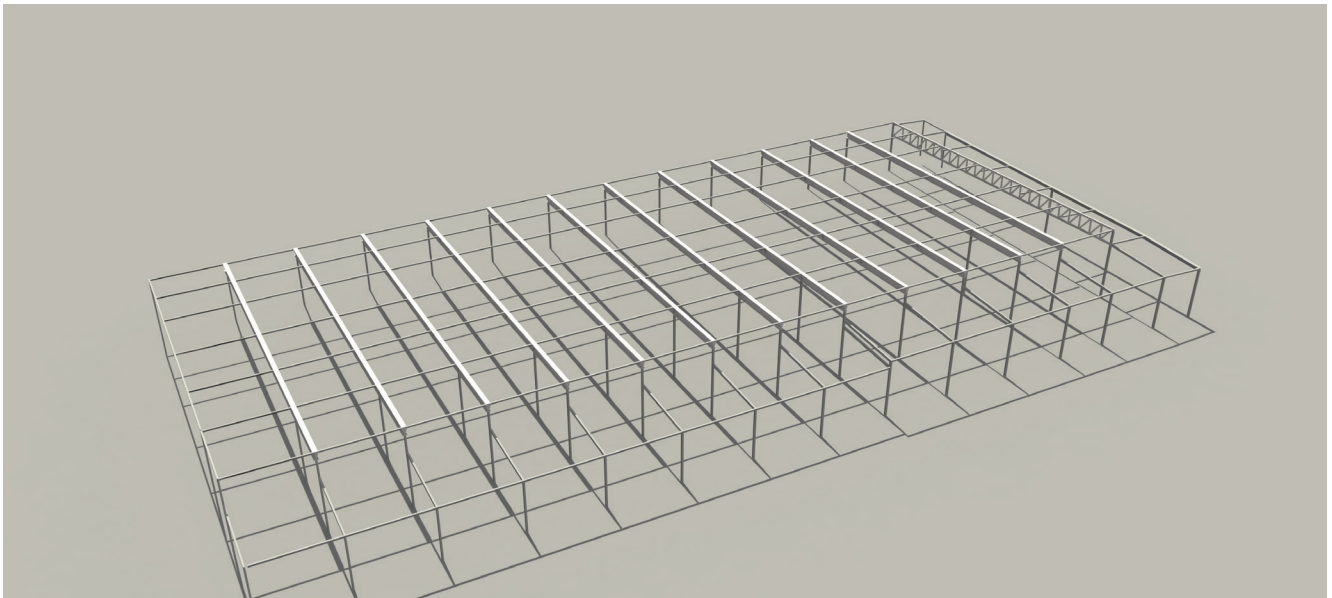


Fig. 76 : Change of the load-bearing structure, top image is the original structure, bottom generic structure (source: own image)

This step would also eliminate half of the corners in the facade, resulting in just four corners to be solved instead of 16, requiring just one homogeneous solution instead of four different solutions. Along with the reduction of the beam size the typologies for the roof can also be reduced. Instead of the roof plates being either in-between or on top of the structure, they will all be moved on top, this reduces the need for extra connecting components and result in easier to reach connections.

The amount of the structure which is generic, is also missing within the model of Durmisevic. The amount of standardisation is important for the deconstruction, this has also been noted by a multitude sources (Crowther, 1999; Guy et al., 2006). The amount of different connections determines the speed on which the structure can be assembled and disassembled, which also reduce the possibility to make mistakes on site. Research has shown prefabrication and standardisation has proven to provide benefits on many levels. As the amount of actions and the caution which has to be taken for disassembly reduces, economical reuse scenario becomes more attainable (Min & Galle, 1997).

The materials currently used within the roof all have a feedstock of 50% or more virgin materials. The end-of-life scenarios, for most of the materials used, show a positive picture. As discussed in the previous paragraph the roof currently exists out of four layers, Load-bearing structure, vapour barrier, insulation, and the roofing membrane. Out of these four layers only 1 layer has no potential for circularity at all. The insulating PIR layer is a fully linear material with no possibility for recycling.

This leaves us to explore new solutions for the roof, as replacing the insulation material has huge implications for the roofing structure. In insulation there are two important factors that will influence your design around it. These factors are:

1. Is the insulation material rigid or soft?
2. At what size does the insulation reach the minimum thermal resistance demanded by the Lidl, which is set at $6.0[m^2 \cdot K/W]$ for the roof.

The roof design the Lidl currently employs requires a rigid insulation material. The roof doesn't allow for a structure on top of the insulation plating. The materials examined for the insulation for the redesign were as followed. The first possible insulation materials are within the Technical cycle of the Circular Economy.

Rockwool

The first material examined is the insulation known as stone wool, for general data about the material the brand Rockwool is used as an example. When you examine the characteristics of the material, the first thing that can be noted is that the material is completely inflammable. They make the insulation from a combination of, basalt, diabase and anorthosite. These materials are all from volcanic rock and are in abundant supply on earth (Rockwool, 2015). The technical specifications of Rockwool (Rockwool, n.d.):

1. Thermal conductivity: $0,038 W/m \cdot K$
2. Density of the insulation $60 kg/m^3$
3. End-of-life: Recycled 100% efficiency 100%
4. Product life 75 years
5. Rigid
6. Price: $92,- €/m^3$

Foamglas

Foamglas is made from at least 60% recycled glass and contains materials that are abundant on our planet, sand, dolomite, and chalk. The product is made from only technical materials and doesn't contain any float gasses. The glass has the following specifications (Foamglas, 2017):

1. Thermal conductivity: 0.041 W/m.K
2. Density of the insulation: 115 kg/m³
3. End-of-life: Recycled 100% efficiency 100%
4. Product life 75 years
5. Rigid
6. Price: 380,- €/m³

Recycled cotton insulation

The insulation is made from second hand clothing that can't be used anymore. These cloths are shredded and used in the production of the cotton insulation. These plates contain between 70% and 85% cotton fibres. The rest of the panel is a polyester fibre to bind it all together and a chemical treatment against insects and mould.(ECO, 2018b):

1. Thermal conductivity: 0.038 W/m.K
2. Density of the insulation: 18 kg/m³
3. End-of-life: Recycled 100% efficiency 100%
4. Product life 75 years
5. Soft
6. 70,- €/m³

The eventual choice for the insulation material is Rockwool , though the current material has almost no recycled feedstock, the earth produces far more than we are currently consuming. It also shows the current bottlenecks for the MCI and the principles for the Circular Economy, the recycling for rockwool isn't of high necessity as the production of new feedstock or recycled feedstock has almost no impact on the carbon footprint(Rockwool, Personal communication, 14-05-2018). Rockwool falls in the technical cycle, though our planet produces the resource for Rockwool as if it is renewable.

The MCI for the technical redesign results in the following values:

Step1: Calculate Virgin Feedstock

Material	M(x) (kg)	F _R	F _U	V (kg)
Steel Hexagon plate	6.9	0.6	0	2.76
Vapour barrier	0.2	0	0	0.2
Rockwool	18	0.2	0	14.4
Derbipure	3.2	0	0	3.2
Total				

Step2: Calculate Unrecoverable Waste

Material	M(x) (kg)	C _R	C _U	W _o (kg)	E _C	W _C (kg)	E _F	F _R	W _F (kg)	W (kg)
Steel Hexagon plate	6.9	0.7	0.29	0.069	1	0	1	0.6	0	0.069
Vapour barrier	0.2	0.05	0	0.19	1	0	1	0	0	0.19
Rockwool	18	1	0	0	1	0	1	0.2	0	0
Derbipure	3.2	1	0	0	1	0	1	0	0	0
Total										0.259

Step3: Calculate Linear Flow Index

Material	M(x) (kg)	V	W	W _F	W _C	LFI
Steel Hexagon plate	6.9	2.76	0.069	0	0	0.205
Vapour barrier	0.2	0.2	0.19	0	0	0.975
Rockwool	18	14.4	0	0	0	0.4
Derbipure	3.2	3.2	0	0	0	0.5
Total						0.330947

Step4: Calculate Utility Factor

Material	L	L _{AV}	U	U _{AV}	X	F
Steel Hexagon plate	20	75	1	1	0.266667	3.375
Vapour barrier	20	40	1	1	0.5	1.8
Rockwool	75	75	1	1	1	0.9
Derbipure	20	30	1	1	0.666667	1.35
Total						

Step4: Calculate MCI

Material	LFI	F	MCI* _p
Steel Hexagon plate	0.205	3.375	0.308125
Vapour barrier	0.975	1.8	0
Rockwool	0.4	0.9	0.64
Derbipure	0.5	1.35	0.325
Total	0.37		0.52

Table 3 : Material Circularity Indicator of the technical redesigned roof(source: own image)

With the change of insulation material the Material Circularity Indicator didn't change for the better. The Biggest increase is seen in the Linear Flow Index. The reason for the stagnating MCI is the functional life span compared to the technical life span. The materials are used far shorter than is possible. The FPO roofing membrane can be made fully circular as well with the right contracts with the suppliers. Though the NIBE gives the most likely end-of-life scenario of FPO to be incineration, suppliers will usually take back their roofing membrane for recycling, since the introduction of the roofcollect program in Europe(roofcollect, n.d.). Though for this case the Derbipure is applied, as it's application actually is known to stay within the biological cycle. The supplier stays responsible for the end-of-life of the product.

The disassembly potential for this redesign hasn't been improved much as the only changes have been in the materials used. The green redesign will focus on the use of sandwich panels instead of loose elements and materials. Redesigns to the build-up would quickly start to overlap with materials in the biological cycle. Because of this reason the redesign for construction, materials and planning has been done on the Green redesign only. As the results would overlap. This is why the technical redesign scores badly on circularity. Reuse is made almost impossible as the roof can't be disassembled.

6.3. Green Redesign

The redesign for the green roof starts with a few different notions than the first redesign. Instead of relying on materials from the technical cycle, the roof will be designed from materials mainly from the biological cycle. In this case the roofing systems isn't the only part redesigned, the main load-bearing structure and façade are also included in the redesign. The Structure gets a complete overhaul. The roofing system in this case consist primarily out of pre-manufactured components which don't need machining on site. The load-bearing structure and the skin system are completely separated, the load-bearing structure is made in such a way it doesn't rely on the skin for structural stability.

The green redesign examines the possibilities to further change the roof design. The Lidl supermarkets are characterized by a flat roof, also called low sloped roof. The angle of a roof greatly determines which materials can be applied as the roof cladding. The diagram below shows the influence on roof slope on the materials which can be used. The low slope roof only has roofing membranes as the possible solution.



Fig. 77 : Inside render of the green redesign (source: own image)



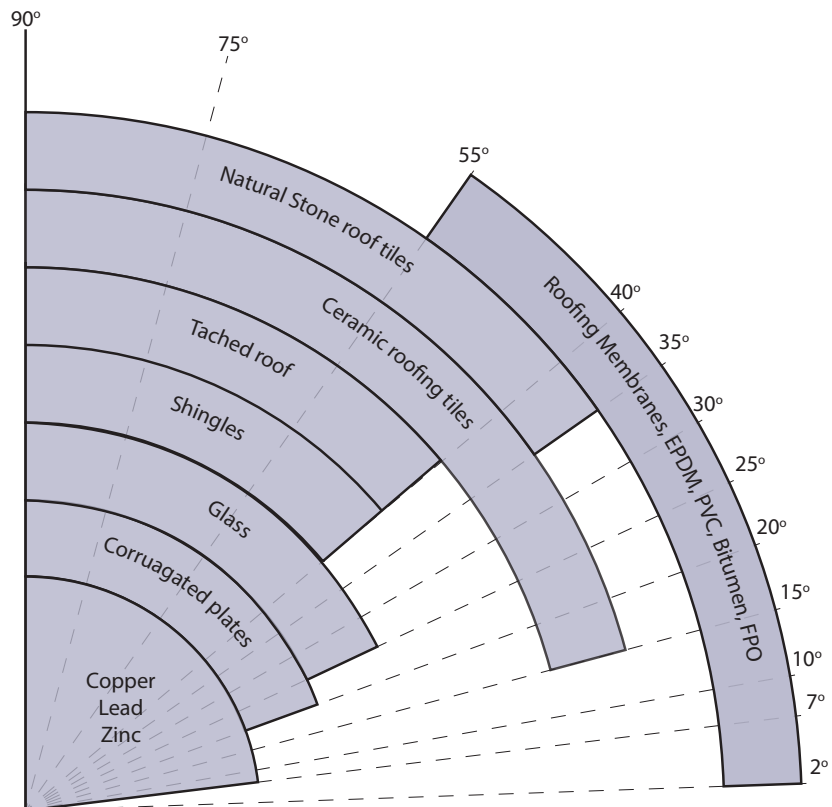


Fig. 78 : Roof slope and cladding as defined by jellema (source: own image)

The roof slope dictates the materials, through this the roof shape has already a large influence of the circularity. The slope used by the Lidl results in the choice for a roofing membrane, which must be one homogeneous closed layer. Any gaps in the material result in leaks in the roof, with premature deterioration and risk of mould as a consequence. The size of the roof, which is 30m by 70m, ensures multiple roof membrane sheets are needed. These sheets need to be adhered or welded together to create a homogeneous surface, as they only come in rolls of 15m by 2m(Sika, 2016).

The first choice needs to be made in the slope of the roof, currently the Lidl uses a slope of 10, showing the membranes work even at such an angle. Increasing the slope of the roof would greatly increase the choice in cladding. Cladding isn't the only factor, which shows benefits for applying a sloped roof. The Lidl wants to add solar panels to their structures to provide a part of the energy demand. Currently the Lidl adds the solar panels by using a separate aluminium sub structure. By taking advantage of the slope of the roof the panels could be integrated instead of needing an additional structure. Research has shown the optimal angle for the solar panels would be 30o, when facing south(Siderea, 2010).



Fig. 79 : Lidl roof, with added solar panels(van Rompaey, 2016)

By using a roof on the optimal angle for the solar panels, the need for an additional sub structure can be avoided. The introduction of this angle would mean an increase of the surface of the roof by 16%, which doesn't sound as to much, but the volume of the supermarket would more than double. The easiest solution for this would be the use of a sawtooth roof, this would mean that the plan would still make use of the slope but would try to avoid the increase in height as much as possible. It would also result in a slight reduction in solar gain as the roof obstructs part the solar panels when the sun is below the 30° angle.

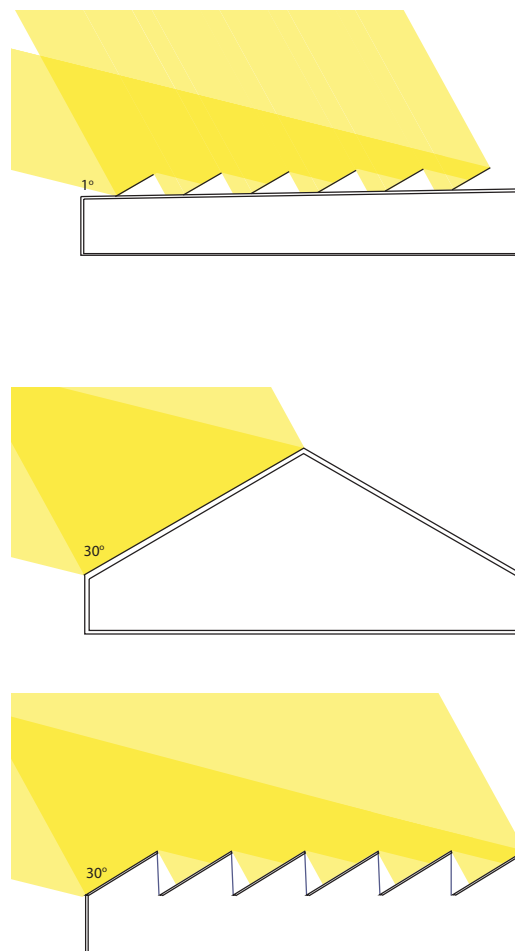


Fig. 80 : Main roof types applicable to the Lidl (source: own image)

The sawtooth roof would provide extra benefits, as it can be used to provide northern lighting in the supermarket, reducing the energy demand for lighting. The Lidl avoids direct sunlight, as the UV in the light can degrade products at a faster rate(LIDL, Personal communication, 20-03-2018). Northern light doesn't have this issue, as it is indirect sunlight. The sawtooth roof reduces the volume, though it has got a larger surface area than its counter parts, with an surface area 50% larger than the original. The sawtooth roof has been used in many factory buildings over the ages, before electrical lighting the roof provided the much needed visibility in the factory halls. The many angles and corners are prone to leaking, making good and rigid detailing a necessity(Grier, 2016).

The choice for the redesign falls on, either a design with the low sloped roof or sawtooth roof. While many more shapes and sizes can be discussed as possible typologies, these usually increase the volume and surface area of the design, resulting in a far larger necessity for cooling and ventilation.

The low sloped roof has the benefit that it has the smallest volume and smallest surface area compared to the other roofs. Its largest counter argument is that it is prone to leaking, as the flat roofing allows water to easily stay for a longer time on the roof instead of flowing off through gravity. The only solution for its cladding is, as previously discussed, the use of a membrane as it needs to be completely water tight. The box structure results in a small amount of corners which need to be solved. Each of these can be solved in the same way as the roof is completely generic. Problems arise for each of the vertical penetrations which have to be made through the membrane. Each of those results in a part which can leak if it's detailed or adhered badly.

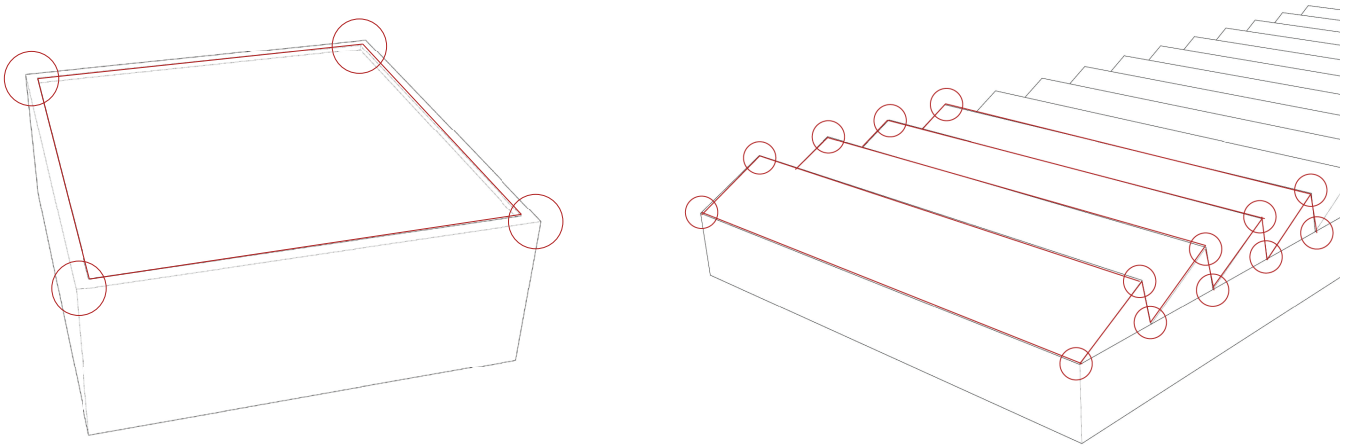


Fig. 81 : Flat roof corners and edges compared to sawtooth corners and edges(source: own image)

The sawtooth roof provides many benefits, the natural angle in the roof can be used for solar panels, omitting the need for a sub-structure. Glass can be added to the northern side, allowing light to enter, thereby reducing the need for artificial lighting. The benefits come at a cost however, the surface and volume both greatly increase, requiring more materials than the original. The sawtooth introduces a multitude of extra corners and edges all prone for leakage if they aren't installed properly. The sawtooth roof is dependent on its orientation. The solar panels need to be located on the south side, while the windows always need their orientation on the north side(Grier, 2016). This high dependency on its orientation is the reason why the sawtooth roof is not chosen for the redesign. The low slope roof is the more generic solution compared to the saw tooth roof. While the low slope roof needs to be completely covered by a watertight layer it can be built anywhere in the Netherlands, enabling easier reusability of the more expensive components.

6.3.1. Low slope green roof

The generic structure of the low slope roof allows for easier reuse. The design isn't influenced by the orientation, as the functions are represented by independently orientable parts. By integrating the sub structure of the solar panels with the roof system, the reusability becomes limited, as it is depended on the orientation of the site.

As the analysis of the original Lidl's roof structure and their Specification shows, there are many facets which could be improved on their circularity as the overall score is low. The materials employed by the Lidl aren't inherently the issue. The problem lies more in the premature obsolescence. Many materials are demolished before their technical service life is on a third, which is especially clear in the analysis of the Specification. This is unfortunate and unnecessary. With over almost 420 stores in the Netherlands (Distrifood, 2018). Every 8 years their Space Plan gets updated, enabled by a complete indoor demolition (Lidl, personal communication, 08-06-2018). Every 20 years a store needs a complete renovation, resulting in Skin, Services and Space plan being mostly demolished and updated. With this knowledge we can assess that every year the Lidl has to fully renovate at-least 20 stores and partially renovate 30 stores. On top of that they build 5 new stores each year. This shows opportunities for reuse, making use of the full value of the materials. The main goal of this redesign is to show how to implement the principles of the Circular Economy through the use of the assessment methods discussed, the Material Circularity Indicator and the Disassembly Potential. The main focus is on the three principles:

- Design out waste and pollution
- Keep products, components, and materials at their highest value and in use
- Regenerate natural systems.

The principles and assessment methods are applied to the low slope roof, with an emphasis on the biological cycle. The layers employed in it can fulfil all of the functions desired by the Lidl, except for the northern lighting. If there is demand for the lighting, changes can be made to the panels. This would allow the Lidl to use prefab skylights. This results in a building system based on four materials. The materials have all been chosen for their high circularity, shown by their MCI. The resulting design can be seen in the Floor plans and sections.

6.3.2. Material Circularity Indicator

All material choice happened through the use of the MCI equations. The focus in the analysis of the original design lay on the Structure and the Skin layers. The redesign focusses on these layers as well. While in the design process the multiple layers and construction principles were addressed in tandem, the report examines them from their position in the design, from longest functional life span to shortest functional life span.

Structure:

The first part to address in the redesign, is the load-bearing structure, as it has the longest functional service life span. There aren't many materials which can fulfil the load-bearing function on this scale, especially materials from the biological cycle. In the biological cycle, this usually means the load-bearing structure will be fulfilled by woody materials. According to research the shift from concrete, brick, aluminium and steel towards wood has many positive impacts(Oliver, Nassar, Lippke, & McCarther, 2014). The only downside to wood is that it requires intensive management of the forests, to ensure they aren't harvested faster than they renew and are depleted. Currently there is over 385 billion cubic meters of wood in forests around the world. Each year an additional 17 billion cubic meters is added to that total, we as a species use just 3.4 billion cubic meters. The rest of the wood is lost to rot, fires and forest densification(Oliver et al., 2014).

Over the years wood has been a reliable building material, and it has only gotten stronger with advancements in engineering. Particle board, plywood, and engineered timber, each have greatly advanced the possibilities of the specific material. These new types of engineered wood are made possible through the use of strong adhesives, the adhesives have been on a formaldehyde basis for the past decades. Formaldehyde is a toxic substance, when applied to the wood it prohibits the material from re-entering the biological cycle, the material becomes a part of the technical cycle instead. This happens as the material can't be returned to the biosphere through conventional composting, incineration becomes the only alternative to remove the toxic adhesives(EPA, n.d.).

A new movement has been forming, providing new biodegradable and bio-based solutions for our building materials. Timber and plywood just as strong as their technological counterparts, but made with biological adhesives. These biological variants allow performance on the technical cycle within the biological cycle. The product used as a reference for the load-bearing structure is Accoya® glulam. This product is based entirely in the biological cycle, this results in a slightly shorter technical service life then other load-bearing materials(Hess, n.d.).

This biodegradable engineered wood is the main component for the load-bearing structure. Accoya® laminated timber. This allows the structure to be completely compostable at its end-of-life(Hess, n.d.). Compostation isn't the favourable end-of-life scenario, reuse and remanufacturing are the preferable scenarios. When the beams reach the end of their technical life span, the beams should be cascaded as feedstock in lower value applications. All these cycles should stay within the biological cycle. The wood should keep cascading until all value of the wood has been depleted. After it's depletion the wood should be returned to the biosphere by composting.

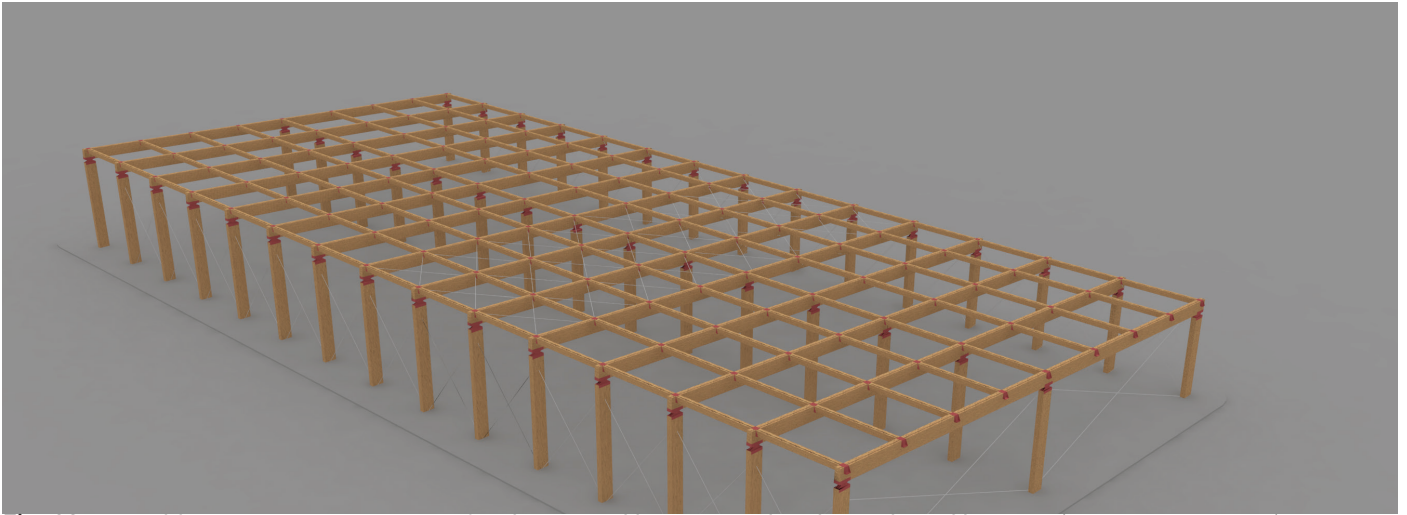


Fig. 82 : Load-bearing structure, Accoya® Columns and beams, steel nodes and wind bracing. (source: own image)



Fig. 83 : Sculpture fingers made with Accoya® glulam(Hess, n.d.)

In chapter 4 the assessment methods were discussed, one of the shortcomings is the difficulty to determine the MCI for bio-based materials. Due to the inherent biological nature of the materials, the materials slowly lose quality and value over time. It is not possible to recycle these materials through economical processes and reinstate their value as if they were just harvested (Ellen MacArthur Foundation, 2013). The only solution is to cascade the materials into new functions, which demand lower quality resources. The Accoya® beams can be cascaded into biological particle boards (Maccarini & Avellaneda, 2012) or the material can be shredded and used for the ECOBoard until it finally becomes a cardboard source and is composted after its last use.

The feedstock for the material is fully regenerative, and due to it being placed in the biological cycle the beams can be returned to the biosphere through composting. The material itself can be used in other applications after the end of its technical service life, if the functionality runs out for the Lidl. The beams can be reused in other applications, they can be sanded on the edges and reused. All the structural elements, throughout the design, are made from the Accoya® glulam. The whole load-bearing structure is made with the glulam, except for the connections and wind bracing, which are made from steel.

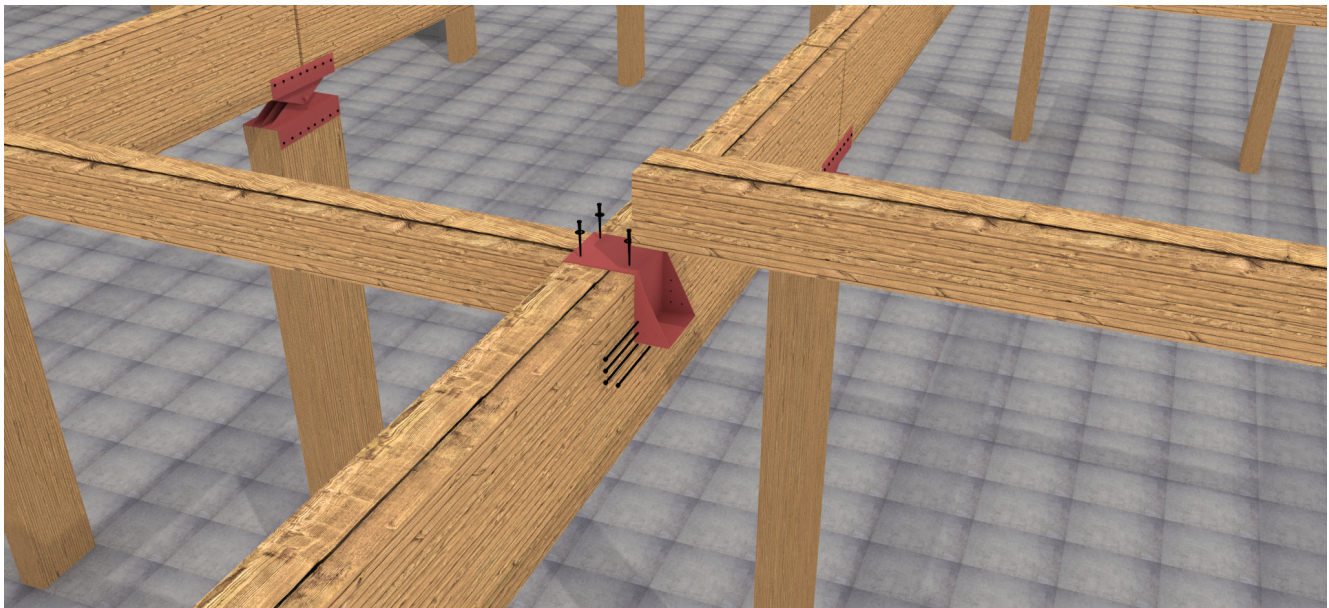


Fig. 84 Wood beam to truss connection (source : own image)

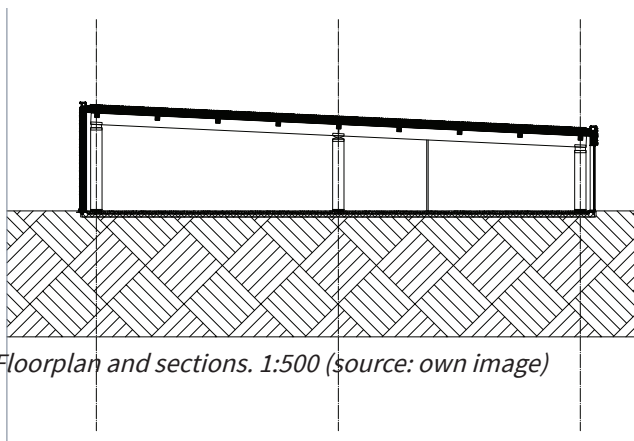
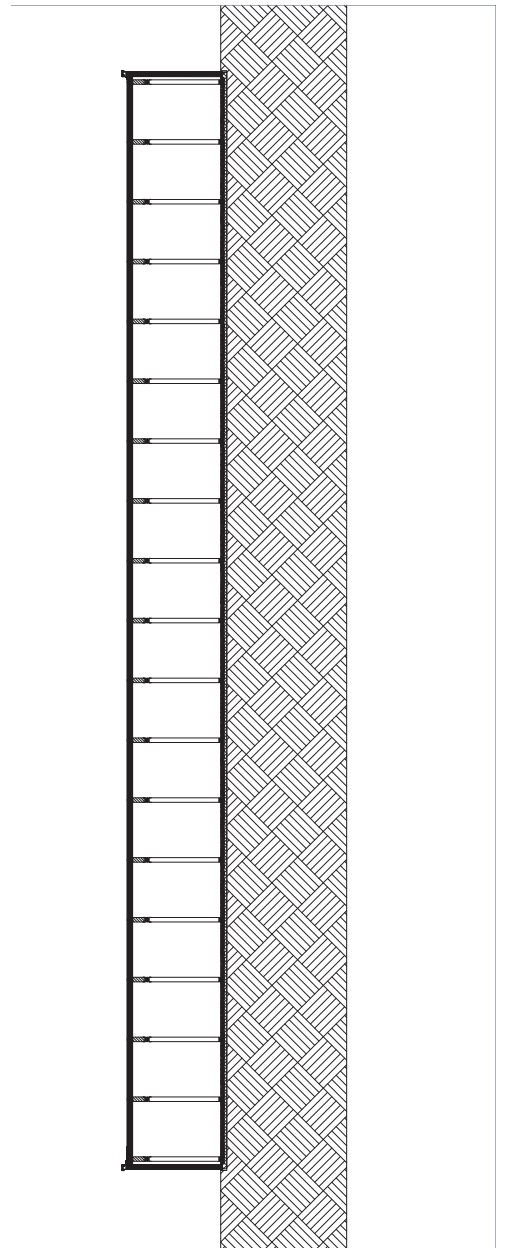
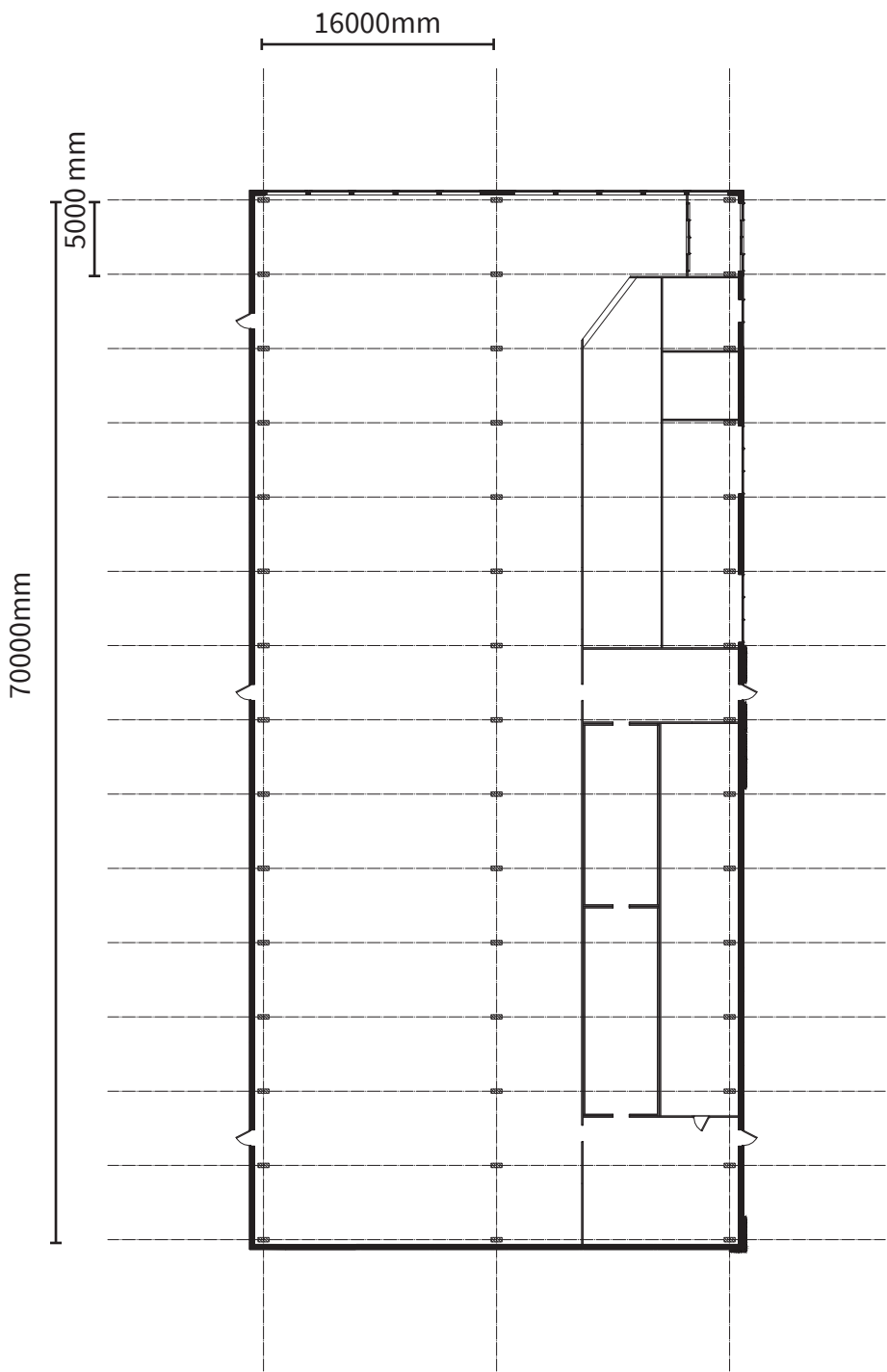


Fig. 85 : Floorplan and sections. 1:500 (source: own image)

The roof structure isn't connected directly to the load-bearing structure, hereby reducing the amount of damage which will be done to the beams. The system is connected to the beams, spanning between the main load-bearing structure instead, which are smaller in size and easier to replace. Reducing the damage to the main structure, allowing for higher value beams to be reused. The horizontal beams are used for all connections which need to be made to the load-bearing structure.

Skin:

The roof system itself consists out of sandwich panels. These panels fulfil all major functions needed in the roofing system except for the water protection. The functions which can't be supplied by the panels, are added on top of the panels. The roofing membrane which makes the whole structure water tight, needs to be added separate for a low slope roof.

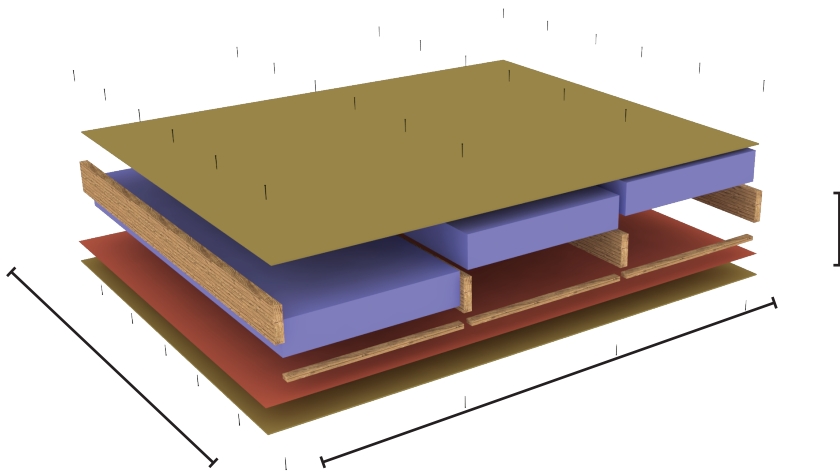


Fig. 86: Sandwich panel exploded view. (source: own image)

The panel is constructed without adhesives, the boards are screwed on to wooden beams, which ensure the structural function of the panel. In-between the lower board and the beams the vapour barrier is positioned. Between the wooden beams the insulation is placed. The thickness of the insulation is higher than would be demanded by the general formula, as the wood has a lower insulating value than the insulation material.

For the wooden plate material, the design makes use of ECOBoards. These boards are made from agricultural waste bonded by a low formaldehyde adhesive, they can be fully recycled into either new ECOBoards or they can be composted at their end-of-life (ECOBoards, n.d.). As shown by tests the ECOBoards has the same density as plywood, it has the same Young's modulus and a comparable life cycle expectancy.

The insulation material is the only choice for which a multitude of different materials is available. For the construction, the vapour barrier, and the roofing membrane there isn't much of a choice. For the structure and the roofing membrane there is currently just one option. For the vapour barrier there currently is no comparable option as all. Due to the structure of the sandwich panel, the insulation doesn't have to be rigid, this allows for even a broader choice in material. The same options are described as in the previous paragraph, besides the biological materials also a few materials from the technical cycle are examined for comparison.

Technical cycle

Rockwool

The first material examined is the insulation known as stone wool, which has unique properties. When you examine the characteristics of the material the first thing that can be noted is that the material is completely inflammable. Rockwool was chosen as a representation for the possibilities of the insulation. They make the insulation from a combination of, basalt, diabase and anorthosite. These materials are all from Vulcanic rock and are in abundant supply on earth(Rockwool, 2015). The technical specifications of Rockwool(Rockwool, n.d.):

7. Thermal conductivity: 0,038 W/m.K
8. Density of the insulation: 60 kg/m³
9. End-of-life: Recycled 100% efficiency 100%
10. Product life 75 years
11. Rigid
12. Price: 92,- €/m³

Foamglas

Foamglas is made from at least 60% recycled glass and contains materials that are abundant on our planet, sand, dolomite and chalk. The product is made from only technical materials and doesn't contain any float gasses. The glass has the following specifactions (Foamglas, 2017):

7. Thermal conductivity: 0.041 W/m.K
8. Density of the insulation: 115 kg/m³
9. End-of-life: Recycled 100% efficiency 100%
10. Product life 75 years
11. Rigid
12. Price: 380,- €/m³

Recycled cotton insulation

The insulation is made from second hand clothing that can't be used anymore. The product is made in France under the brand name Metisse insulation. For the insulation the cloths are shredded and used in the production of the cotton insulation, these plates contain between 70% and 85% cotton fibres. The rest of the panel is made up from a polyester to bind it all together and a chemical treatment against insects and mould.(ECO, 2018b):

7. Thermal conductivity: 0.038 W/m.K
8. Density of the insulation: 18 kg/m³
9. End-of-life: Recycled 100% efficiency 100%
10. Product life 75 years
11. Soft
12. Price: 70,- €/m³

Biological cycle

Sheep wool

Sheep wool has interesting properties, it's a completely natural fibre. In the old NIBE database, sheep wool used to be one of the best choices for natural insulation, this has been changed though. For older calculation sheep wool used to be a waste product that would otherwise end up on the landfill. Sheep were thought to be held for their meat. Due to new calculations that compare the value of the products the wool scores way worse due to the excretions of the sheep during its lifetime. These contain many greenhouse gasses(NIBE, n.d.).

1. Thermal conductivity: 0.038 W/m.K
2. Density of the insulation: 30 kg/m³
3. End-of-life: Incineration
4. Product life 75 years
5. Soft
6. Price: 340,- €/m³

Hemp

The hemp insulation is a completely natural insulation material. Hemp doesn't contain any proteins, because of this reason the material won't have issues with vermin. Unfortunately the material falls into European fire class code E. This means it is highly flammable and will contribute to the fire(ECO, 2018a). The insulation panels are made from 90% hemp and 10% PLA. The technical specifications are:

1. Thermal conductivity: 0.038 W/m.K
2. Density of the insulation: 37 kg/m³
3. End-of-life: the material can't really be recycled, when it reaches its life-cycle end it can be composted.
4. Product life 40 years
5. Soft
6. Price: 150,- €/m³

The eventual choice for the insulation material isn't from the biological cycle. This choice is made because of the favourable recycling efficiency and the almost fully recycled feedstock. This results in the Metisse insulation being the more favourable choice. The material performs better than all the others in pretty much all categories.

The insulation being the last material needed for the sandwich panel the following build-up can be determined:

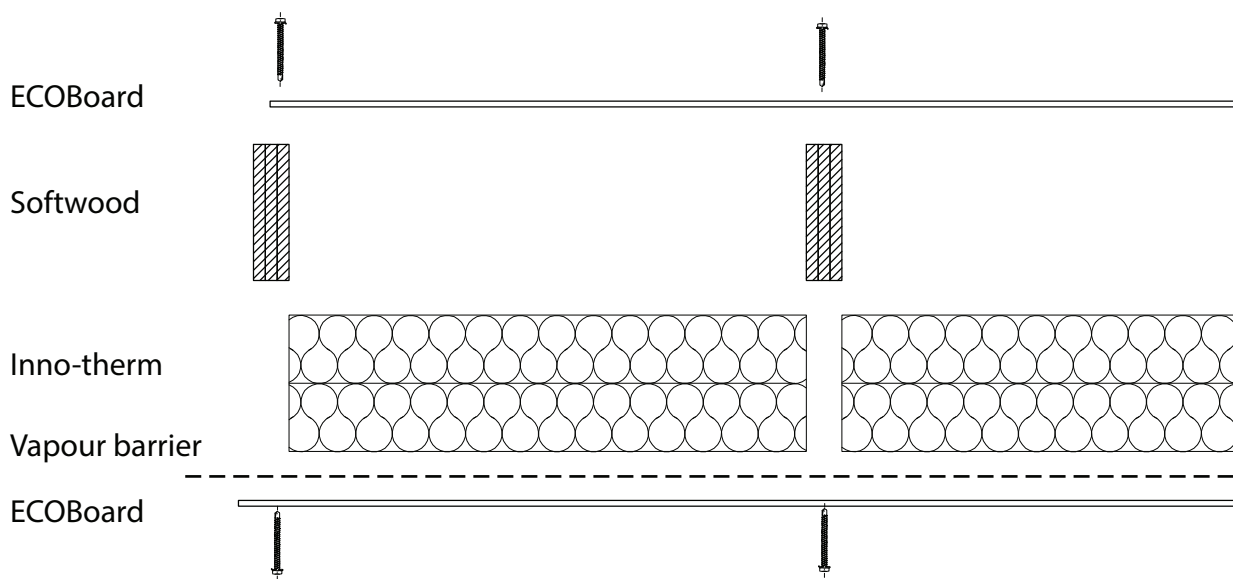


Fig. 87 : Sandwich panel section(source: own image)

Though the sandwich panel isn't fully in the biological cycle, it's still completely disassemble. The materials used, are kept pure as they don't contaminate each other . This allows all materials to be reused independently. The biological materials can be reused, if they still preform at their technical specifications. If that's not the case the biological materials can still be composted or used in a cascaded cycle at their end-of-life.

For the roofing membrane it's a bit more difficult to find an ecological alternative. Currently there seems to be just one that fits the description, Derbipure made by Derbigum. A fully ecological roof membrane, made from a bio-polymer. The bio-polymer consists out of vegetable oils and pine resins. The membrane is 100% natural and a 100% recyclable(Cradletocradle, 2011). Other choices for the roofing membrane would directly end up in the technical cycle of the Circular Economy. On top of the membrane a ballast layer is laid down. This layer ensures the roofing membrane can't be blown off by wind.

The ballasted roof allows the roof to be connected with few mechanical connections. The seams still need to be adhered or heat welded, for leak resistance. The ballasted layer is usually made up from pebbles or gravel. Sedum has also proved to be able to function as a ballast layer. The sedum fulfils three functions, compared to the other ballast layers. Besides its main function the sedum layer works as a water retention layer. The third function is more on an overall environmental level. The sedum layer prevents the heat island effect , as the roof is cooler than other systems. Sedum roofs and solar panels are often used together because of this reason. Solar panels tend to overheat during the summer, the sedum layer cools them down and results in a higher yield for the solar panels(sedum., n.d.).



Fig. 88 : *Sedum roof laying*(grön, n.d.)

With all the materials known, the MCI can be calculated for the whole structure. Because materials from the biological cycle are included a few issues arise. Biological materials can't be easily recycled, over multiple cycles they lose properties, they can only be applied into cascaded cycles. This reason alone makes it difficult to compare the load-bearing structures. If examined as a technical material, the wooden beams perform worse, but because they are compostable and can be used in other biological applications they aren't within the technical cycle.

Still, the new roof has got an MCI of 0.91, due to the high recyclability of all materials. Even when the Derbipure doesn't use recycled feedstock yet, due to its low weight it doesn't influence the formula too much. A fully circular end-of-life scenario already provides a material with an MCI of 0.50.

Step1: Calculate Virgin Feedstock

Material	M(x) (kg)	F _R	F _U	V (kg)
ECOBoard	8.9	97%	0%	0.267
Vapour barrier	0.2	0%	0%	0.2
Metisse insulation	5.04	85%	0%	0.756
Derbipure	1.9	0%	0%	1.9
Total				

Step2: Calculate Unrecoverable Waste

Material	M(x) (kg)	C _R	C _U	W ₀ (kg)	E _C	W _C (kg)	E _F	F _R	W _F (kg)	W (kg)
ECOBoard	8.9	1	0	0	100%	0	100%	97%	0	0
Vapour barrier	0.2	1	0	0	100%	0	100%	0%	0	0
Metisse insulation	5.04	1	0	0	100%	0	100%	85%	0	0
Derbipure	1.9	1	0	0	100%	0	100%	0%	0	0
Total										

Step3: Calculate Linear Flow Index

Material	M(x) (kg)	V	W	W _F	W _C	LFI
ECOBoard	8.9	0.267	0	0	0	0.015
Vapour barrier	0.2	0.2	0	0	0	0.5
Metisse insulation	5.04	0.756	0	0	0	0.075
Derbipure	1.9	1.9	0	0	0	0.5
Total						0.083043

Step4: Calculate Utility Factor

Material	L	L _{AV}	U	U _{AV}	X	F
ECOBoard	75	75	1	1	1	0.9
Vapour barrier	40	40	1	1	1	0.9
Metisse insulation	75	75	1	1	1	0.9
Derbipure	20	20	1	1	1	0.9
Total						

Step4: Calculate MCI

Material	LFI	F	MCI* _p
ECOBoard	0.015	0.9	0.9865
Vapour barrier	0.5	0.9	0.55
Metisse insulation	0.075	0.9	0.9325
Derbipure	0.5	0.9	0.55
Total	0.10		0.91

Table 4 : Material Circularity Index green roof(source: own table)

The roof is heavier than the original, the beam structure alone is 100 kg per meter heavier than the original. The roof panels are also heavier when compared to the original, the green redesign weighs 29.8 kg/m², the original roof weighs 13,6 kg. The difference in weight is caused by the extra height in the structure and the fact that wood has got a lower young modulus.

6.3.3. Disassembly Potential

For the disassembly potential, it's required to look at the complete build-up of the structure, and analyse at the end of the paragraph how this relates to the Disassembly Potential. The structure can be assembled in five steps:

1. Erecting the structure
2. Placing the sandwich panels
3. Placing the insulation and connecting boards
4. Roofing membrane
5. Sedum roof

The first step is the erecting of the load-bearing structure with the base elements.

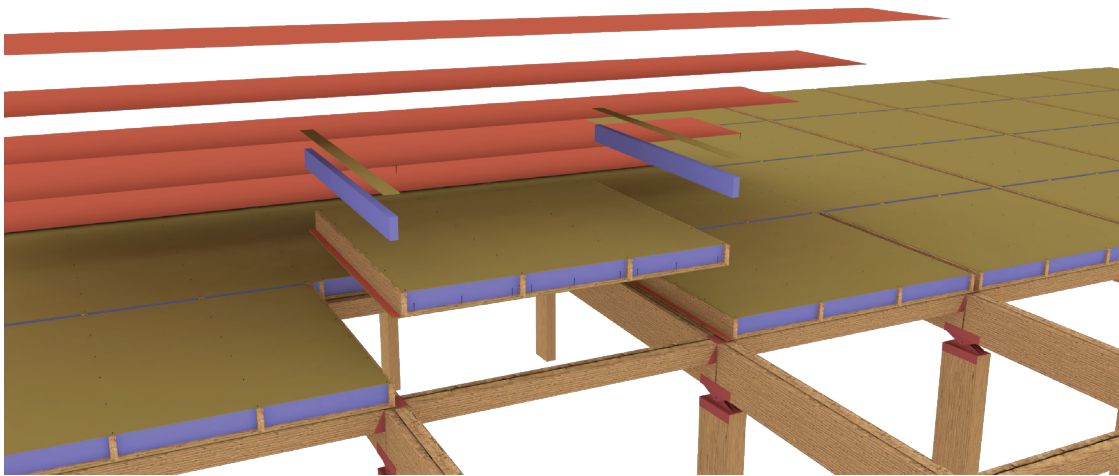


Fig. 89 : Sandwich roof layers (source: own image)

Two types of connections are used within the roof structure, screwed and bolted. Both are reversible and improve the systems prospects of reuse. The methods are comparable to the ones used in the Circl of ABN AMRO. The structure makes use of screws instead of bolting everything, as screws do less damage compared to bolts (Geuijen, n.d).

All the sandwich panels are created off-site, customisation is done in the factory, all panels have vertical penetrations and skylights premade. The size of the panels enables for large openings where needed. Due to them being basic wood skeletons, the knowledge for the assembly is already existing. The roof panels consist out of panels which are 4000 mm wide and 5000mm long. These sizes are chosen as they could be placed on the original load-bearing structure as that structure has the same dimensions.

The beams in the panel run in the length direction, guiding the forces to the sub structure on which they will be placed. The wall panels differ in size. On both long edges the size is constant, on the short edges the size changes over the length. This change in length occurs through the use of the slanted roof. The top and bottom plate of the sandwich panel are also different in size, this size allows them to be assembled and disassembled completely independently from each other.

The vapour barrier sticks out of the panel to allow for overlap during assembly. To ensure the barrier doesn't tear, it's rolled up to the sides of the plate. They arrive per truck to the building site, a truck would be able to contain 16 panels. With 6 trucks the roof structure could be completed. These sandwich panels are then moved by crane, each of the panels weighs almost a 100 kg. A crane is needed to move them on site.

This is also the second step in the process, the sandwich panels are screwed to the base element in the load-bearing structure.

During this step the vapour barriers are unfolded, and on the overlap an ECOBoard with HDPE foil is screwed on tightly. This closes the vapour barriers and ensures the airtightness of the structure.

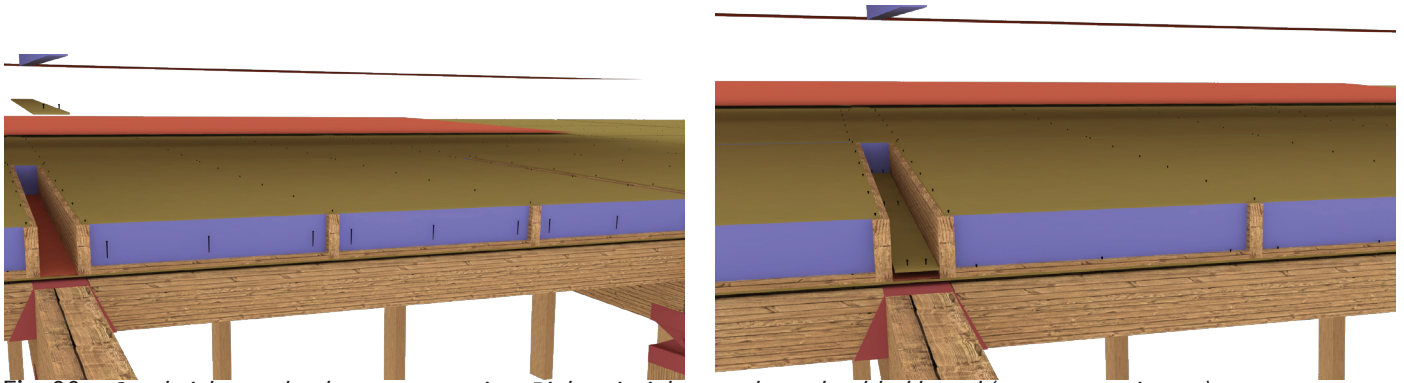


Fig. 90 : Sandwich panel to beam connection. Right: air tightness through added board (source: own image)

On the ECOBoard a layer of Metisse Insulation is placed, this continues the insulating layer and ensures an RC of 6.0. Because the Metisse insulation isn't rigid and can't be walked upon, another layer of ECOBoard is screwed to the top of the sandwich panels. Because the size of the gap we are able to assemble and disassemble the panels on whichever place it is needed within the structure, each panel can be assembled parallel with the others.

These gutters between the panels also provide room for vertical transportation between the layers, through these it is possible to lay cables for solar panels.

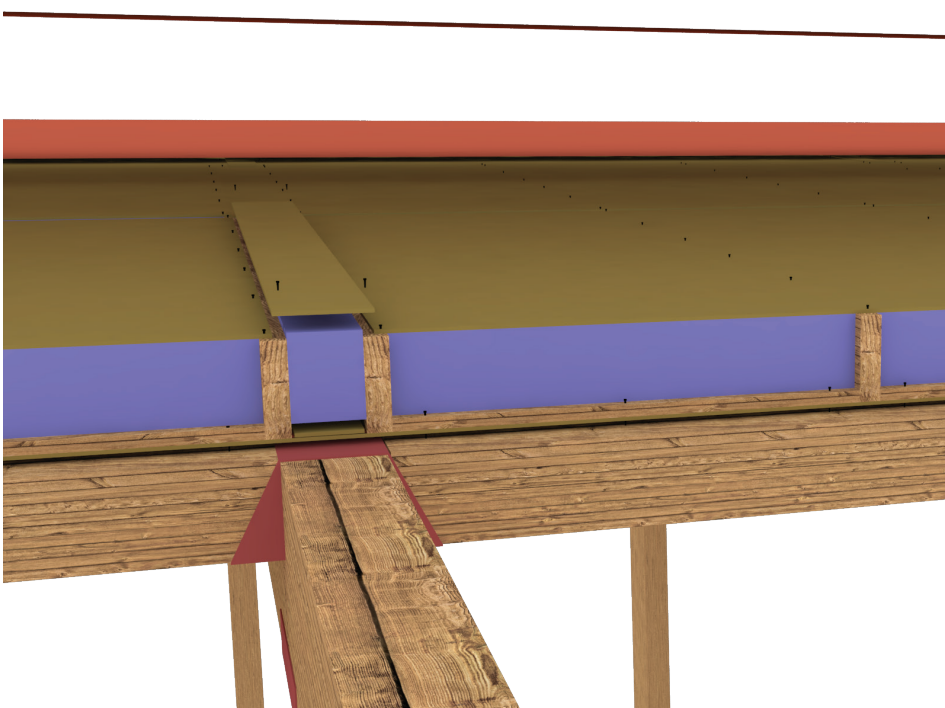


Fig. 91 : Providing a rigid surface for the roofing membrane (source: own image)

After the whole top layer is assembled the roofing membrane can be laid down. Instead of fastening the roof mechanically, the roof is laid loose on the structure. Only a few connections are needed, these are to keep the roofing membrane in place. In a mechanically fastened system the edges still need to be adhered, in the loose laid variant the seams are welded or covered with tape. This system allows for even larger size membranes than a mechanical system. The membrane is kept in place through the ballast layer which is placed on top.

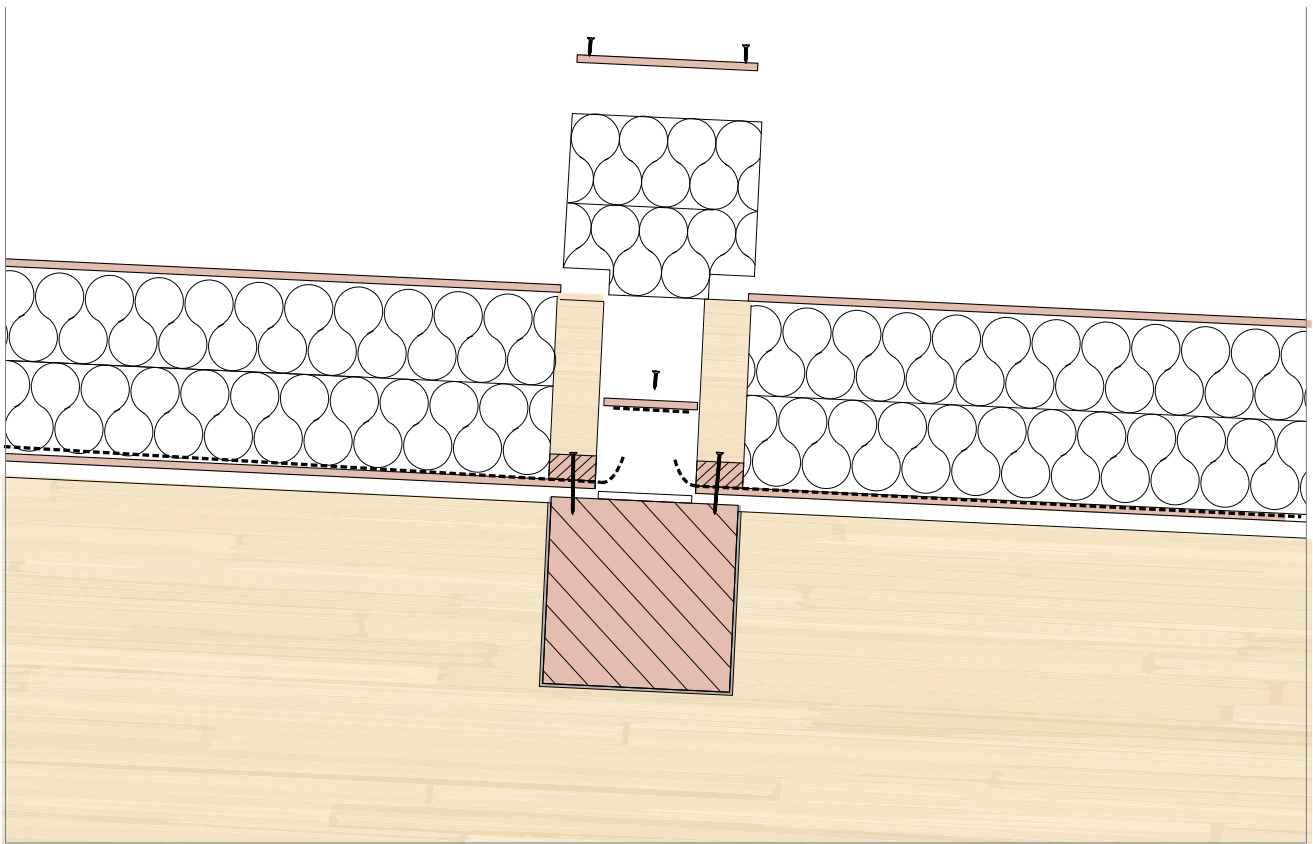


Fig. 92 : Closing the gaps (source: own image)

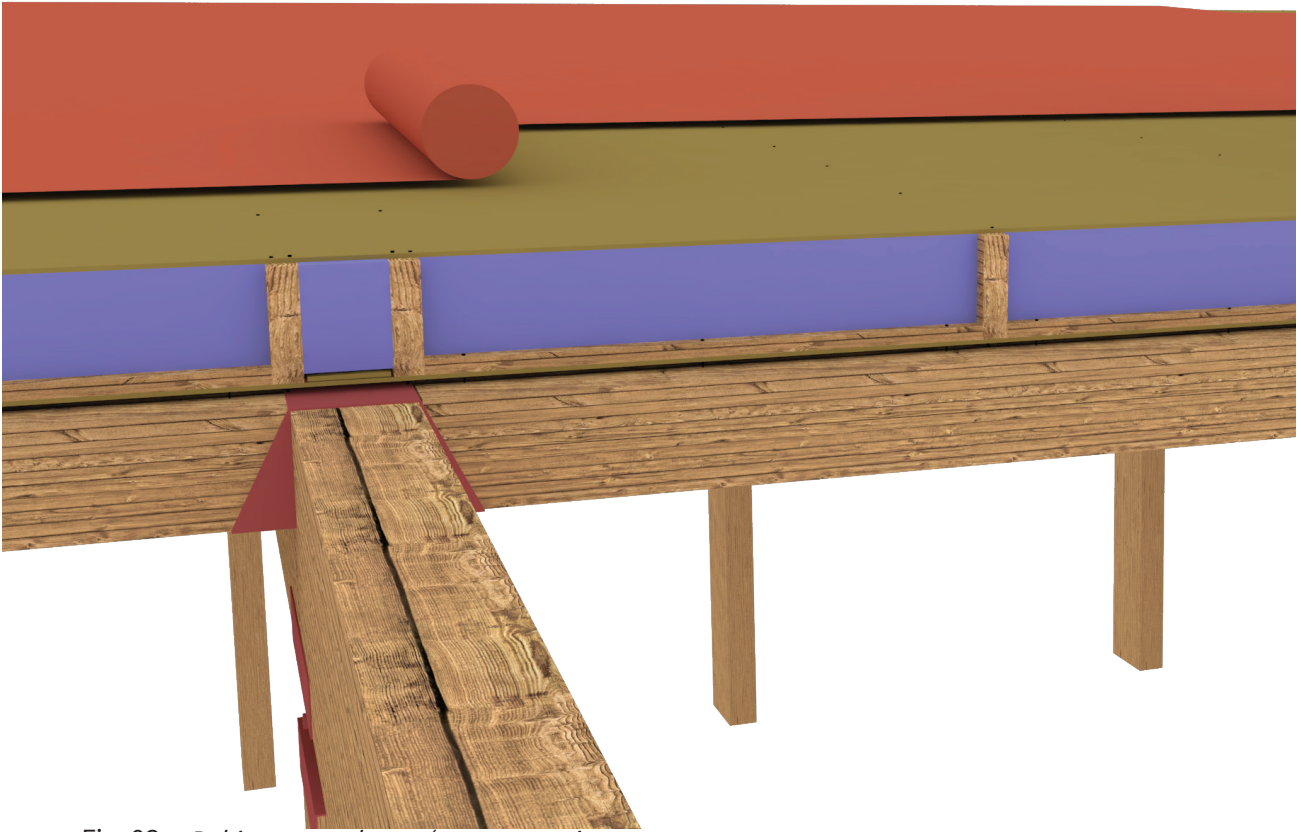


Fig. 93 : *Debipure membrane* (source: own image)

This ballast is the fifth and final step in the assembly, a substrate layer is placed on top of the roofing membrane. On the membrane a layer of soil and sedum is placed. This layer gives the system its water retention and keeps the roofing membrane in place.

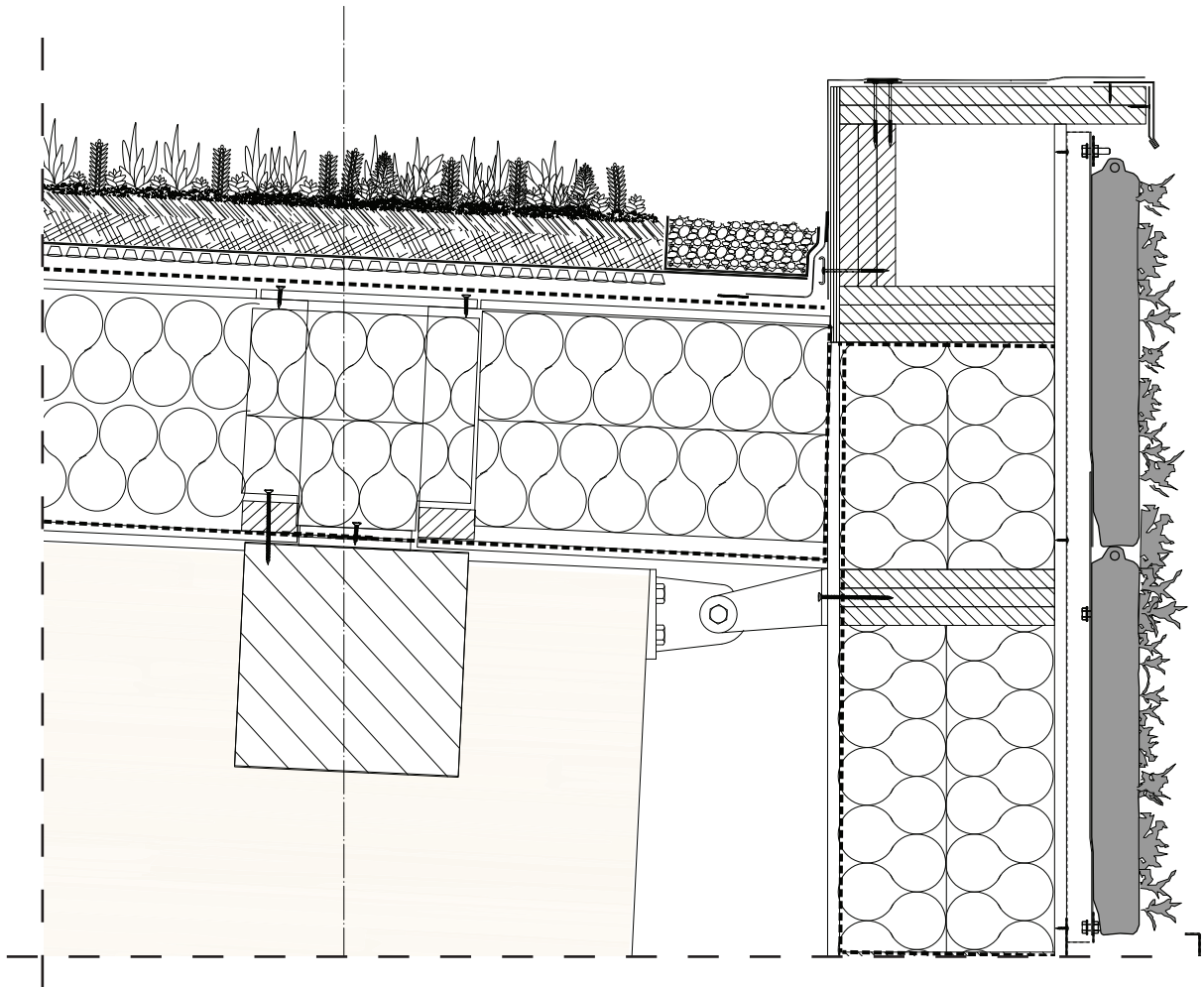


Fig. 94 : Detail A 1:10 (source: own image)

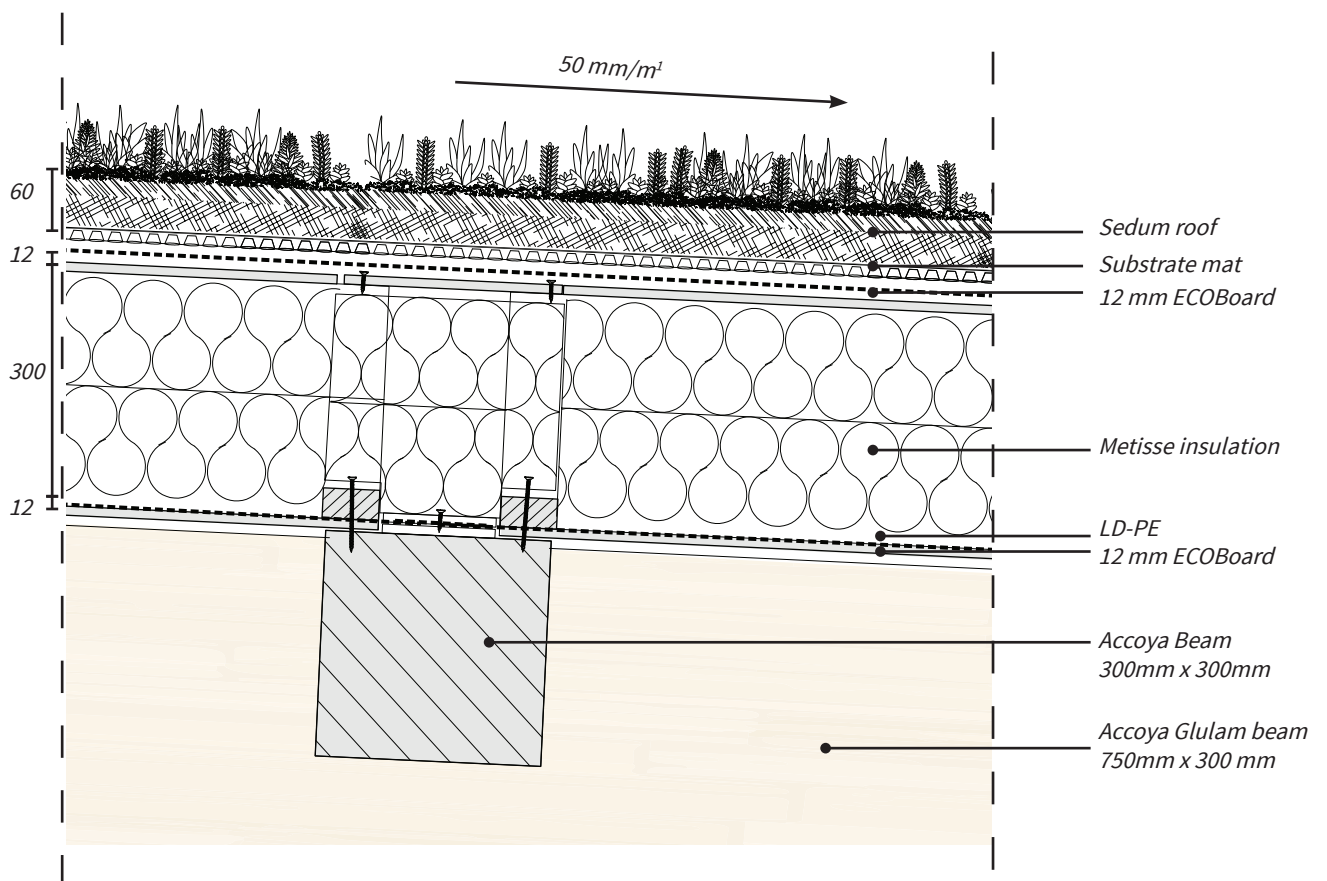
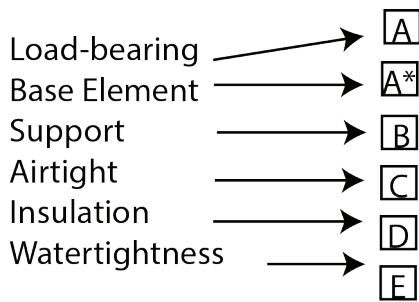


Fig. 95 : Detail B 1:10 (source: own image)

Functional Decomposition(FD):

The structure contains more functions than the original, most of the functions are still in separate elements, and can be changed independently from each other. If it's needed, panels can be interchanged for different ones without disturbing the surroundings, no material fulfils multiple functions. Each of the materials is separable and can be retrieved when a panel needs to be replaced. This separation results in a high score for the element, each of these elements can be deconstructed into their original components, which retain their initial integrity. This goes for all elements except the vapour barrier which will have holes because of the screws. The result is a score of 1(fs) for the Functional separation and a 0.8(fdp) for the Functional dependence.



fs = 1

fdp = 0.8

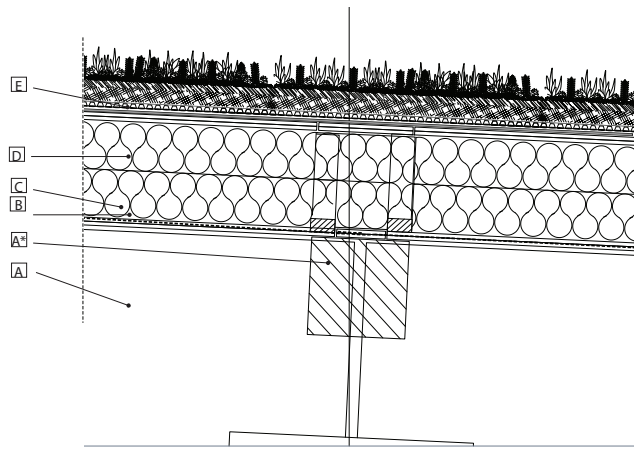


Fig. 96 : Build-up of the Functional Decomposition(source: own image)

Systematisation(SYS):

The structure is build up from components only, the roof and façade can both be made prefabricated. Only the finishing layer needs to be added on site, this applies to both the roof and the façade. For the roof it's the roofing membrane and the ballast layer. For the façade it is the panelling. The design scores higher on this because it makes use of components instead of just elements. This will allow for easier assembly and disassembly. Though the components are heavier than if it were just the separate materials, the build-up will be more clear. Besides it'll allow for easier choice making within the system as the prefabricated elements can be in multiple varieties. The clustering also happens on a functional level, all clusters are made within the roofsystem (c) = 1. All the major functions are separate layers within the system and completely independent from each other. The result is a score of 0.8 for the (st)

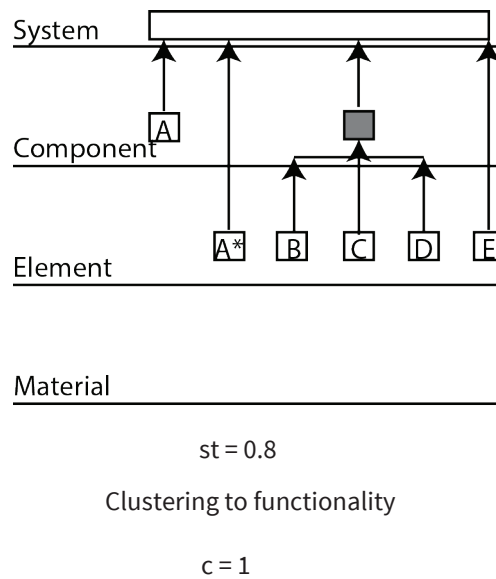


Fig. 97 : Systematisation, prefab components (source: own image)

Base Element(BE):

Within the system, a base element is included, this provides the separation between the Structure and the Skin layer. The base element allows the structure to be changed without interfering with the structural integrity of the building. The same is tried for the panel itself, but within the structural panel the vapour barrier is stuck between the Base Element and the finishing layer. The base elements are completely independent from each other, this allows for independent disassembly. And results in a score 1(be). This can also be seen in the relational diagram below. The base element separates all the other structures.

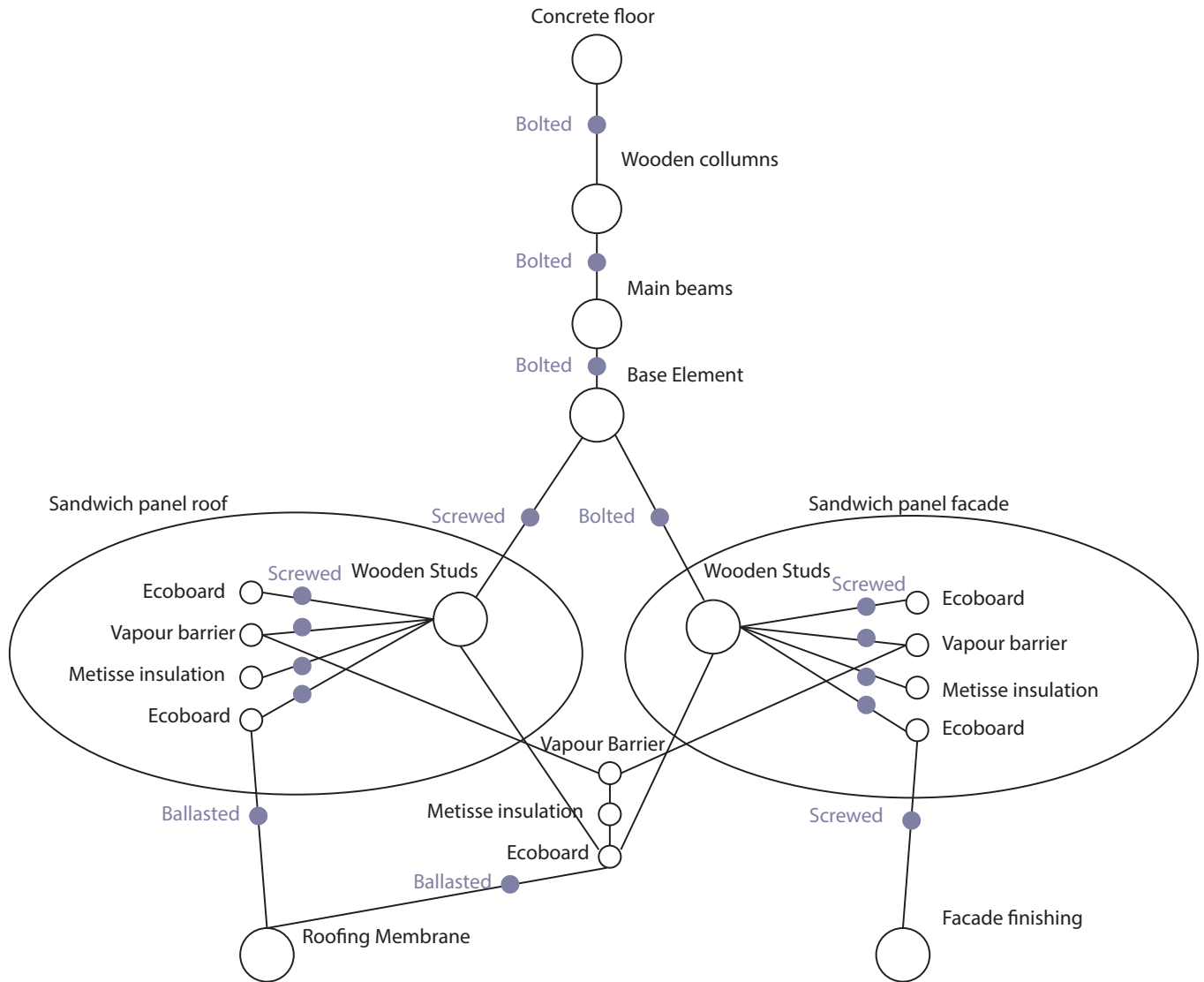


Fig. 98 : Relational diagram, prefab roof and facade substructure (source: own image)

Relational Pattern(RP):

As shown in the relational diagram above, the relations are kept vertical as much as possible. Horizontal relations are still needed, they are needed to provide a constant vapour barrier and insulation. Because of this, there are relations in a very low zone in the diagram. The roof construction also results in relations in a horizontal zone, as they need to be welded together. This results in a score of 0.6 for the relational pattern.

Life Cycle Coordination(LCC):

The elements all have a longer life span than the layer they are implemented in. The roofing elements can last for 75 years if they aren't disassembled. This while the Lidl wants to change their Space Plan every 8 years and their façades every 20 years. The new panels would allow them to strip them back to their basic components and reconfigure them where needed, if a new insulation material is needed it can be upgraded as well. In terms of life cycle to functions the panels last three times longer than is necessary. The structure, according to Accoya, lasts shorter than the sandwich panels employed. Still the Accoya substructure will be usable for 50 years. The shortest lasting material, the roofing membrane, is positioned as the outside layer, the layer can be renewed independent from the rest of the skin. This same principle applies to the façade. This means the score for the total life cycle coordination will end up as a score of 1. All elements have at least an life expectancy of 50 years. The sandwich panels have an expectancy of 75 years.

Assembly(A):

The assembly of the structure can happen almost completely parallel, except for the finishing. This finishing results in a roof and façade that can't be disassembled without removing the roofing membrane. If you want to replace a single component you need to remove, or destroy, that part of the roofing membrane. This results in a score of $a_d = 0.6$ for the structure, as it limits the possibility for disassembly.

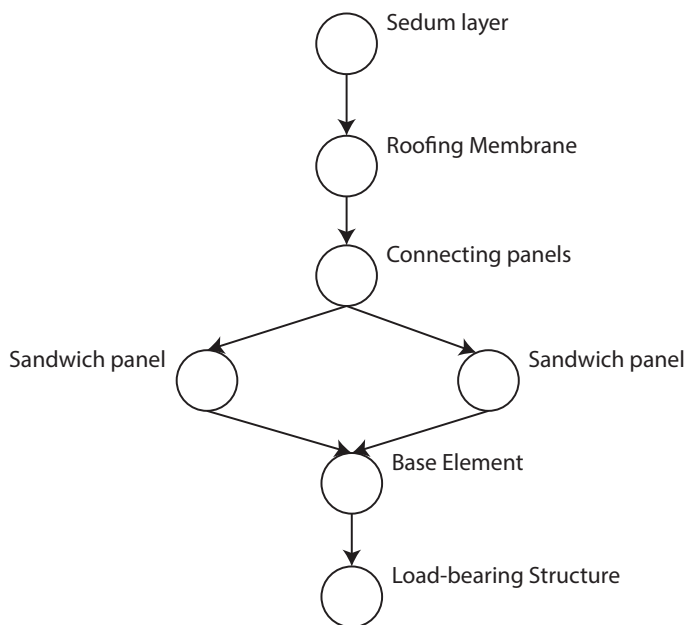


Fig. 99 : Assembly sequence , stuck parallel(source: own image)

Geometry(G):

The geometry is fully open linear for all components. Each component can be installed and remove without interfering with another component. This greatly improves the chances for disassembly. When the function of the supermarket changes, it is possible to change part of the roof panels for ones that allow skylights. It would allow the building to change function, as long as the prefab components are prepared off-site. This results in a $g_e = 1$ as no major component hinders another. The geometry is also completely standardised, resulting in a $s_e = 1$ too.

Connections(C):

The structure has, as shown in the relational diagram, an almost completely reversible assembly. There are only a few major connections to be distinguished within the structure. Almost all of them are reversible. The first connection is the connection between the large load-bearing beams and the Base Element. This connection is made by using an accessory connection device. The trusses make the connection to the beams through a steel element.

The second connection is made between the sandwich panels and the base elements. The sandwich panels are screwed to the beams, the washers used ensure the sandwich plates stay in place and can be assembled and disassembled multiple times.

Water tightness is ensured by an accessory connection as well. A plate with an LD-PE foil is screwed down to close the seams between the foils. This makes the whole connections reversible and the panels disassemblable independent from each other.

The insulation is laid loose between the panels, it is held in its place by the ECOBoard screwed to the top of the sandwich panels.

The only ‘adhered’ layer is the roofing membrane, this makes the connection irreversible without demolishing the layer. The membrane is a loose laid ballasted system. This allows the roof to move under the membrane and requires almost no fixings. The membrane is kept in place through the ballast on top, the roof needs to be calculated to be able to handle the extra weight. The seams between the membranes are welded together. It encloses the whole roof and removes the possibility to disassemble the panels underneath without destroying the whole system. The score for the roof connections are the same as in the original, as the roofing membrane still encapsulates the whole structure. This can also be seen in the relational diagram (fig 96)It results in a score for the tc = 0.6. The fixings are all accessible, the roofing membrane is obstructing these fixings. The only way to reach the fixings is cutting the membrane up at the spot. The after the replacement of the panels the new membrane has to be welded. This gives the accessibility to fixings a score of af = 0.6, you are able to reach the fixings but the damage has to be repaired afterwards.

The tolerance for each panel is kept large to provide distance to disassemble each panel independently, without fearing for the destruction of surrounding panels.

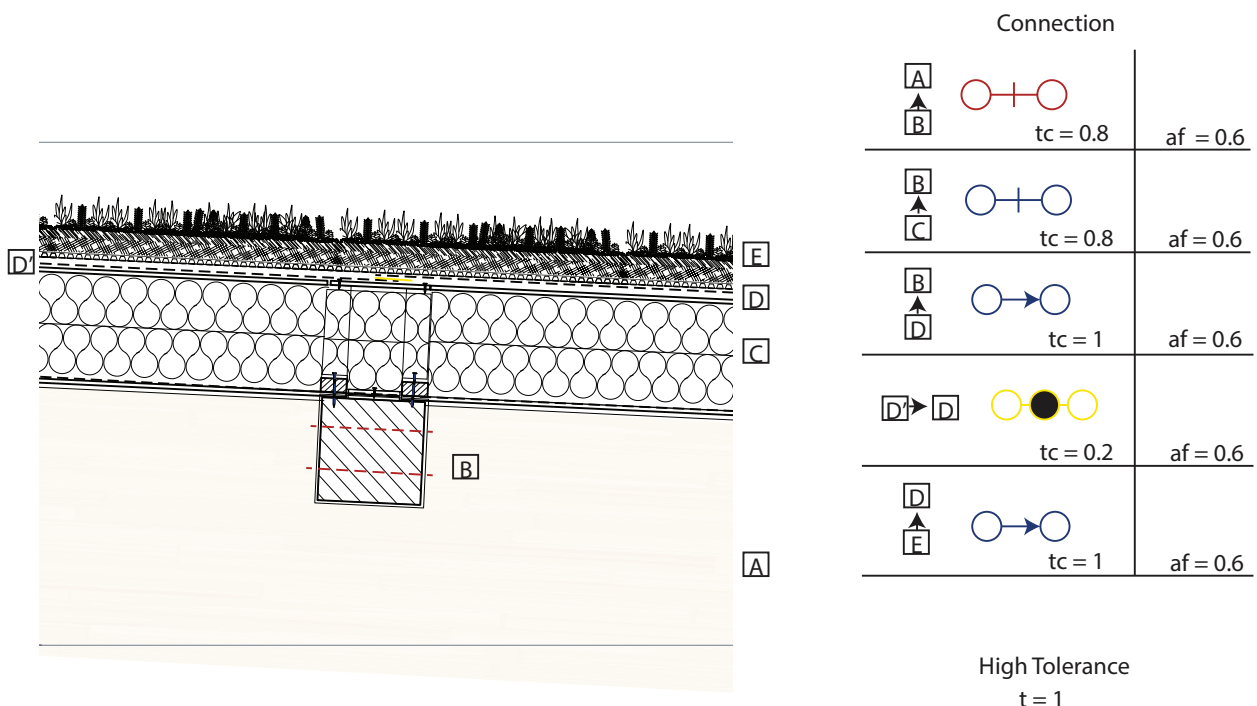
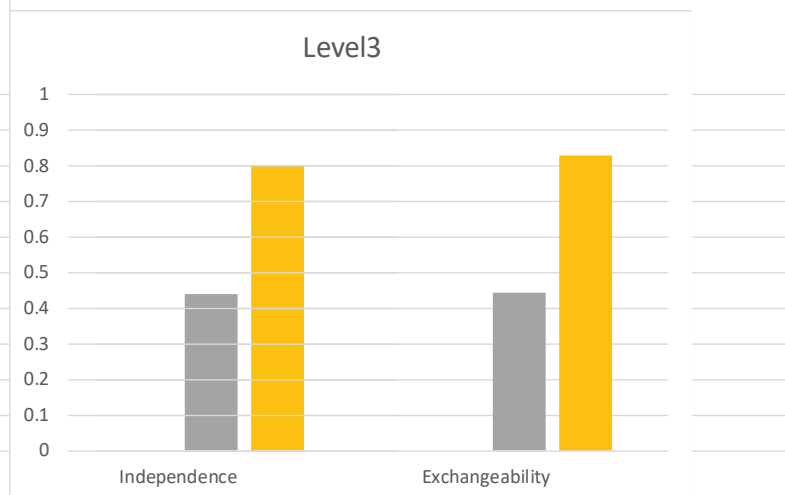
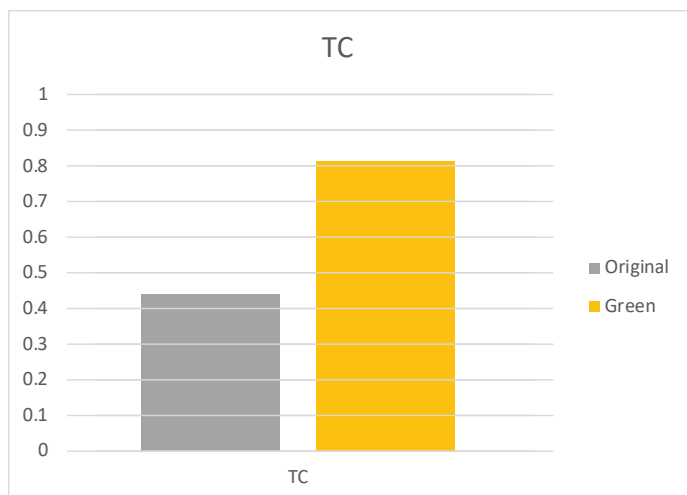
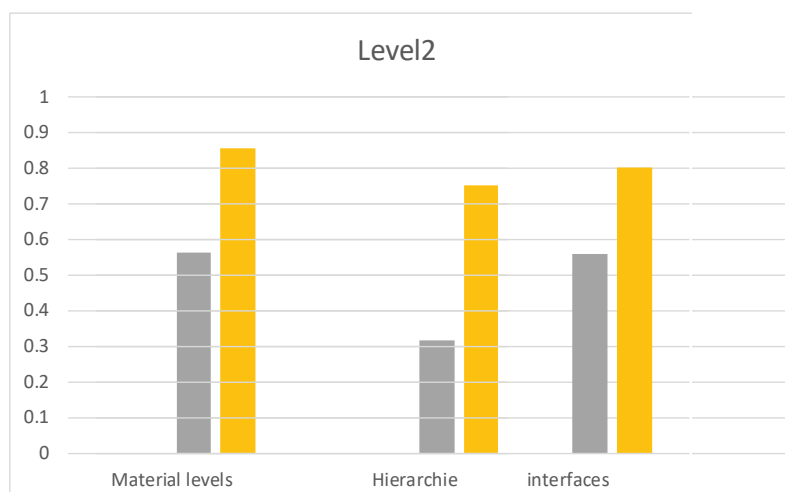
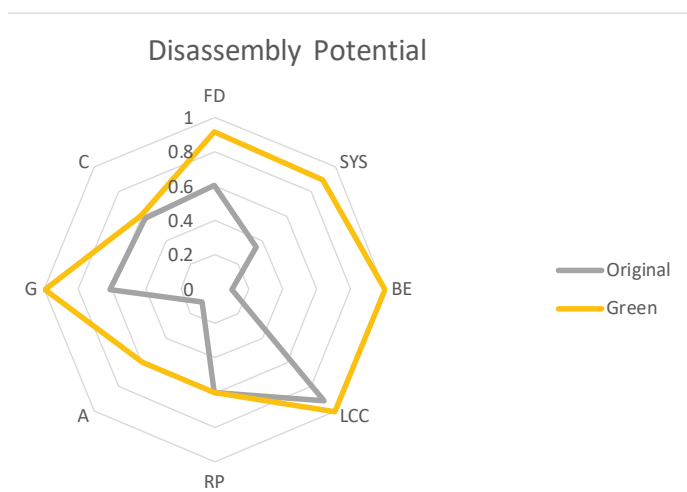


Fig. 100: Connection principles

The result shows on which subjects the green designs has improved. There are still many facets which could be improved upon. The largest areas that allow for improvement, are the Connections and the Relational Patterns. A different system is needed for the water tightness of the roofing. The current system envelops all components and hinders their Disassembly Potential. For the comparisons the ballasted roof is ignored, as it would add extra weight that would influence the MCI's of the materials. The Lidl wants to add the sedum roof to all their supermarkets, as it is an inherent component it would be unwise to take it along in the comparison as it is the same for all designs.

The Transformation Capacity score , the TC of 0.81 predicts almost no waste will be formed during disassembly, between 0% an 30% will be demolished instead of disassembled. Which is to be expected as the only part which needs to be demolished is the roofing membrane. All other layers are all made with reversible connections. The score shows that disassembly will be likely an economical possibility. With the retaining of the value through disassembly reuse is enabled in this new design.



6.3.4. End-of-life scenarios green redesign

The green redesign changes the possibilities for the end-of-life of the Lidl supermarket. Instead of relying on demolition and the contractor to dispose of the waste, The design tries to keep materials as long in use as possible. The result is three scenarios for when a supermarket is renovated.

- Renovating façade cladding
- Reusing the Sandwich Panel
- Remanufacturing the Sandwich Panel

The first scenario is the renovation after 20 years, where the supermarket will retain its function and doesn't require any major upgrades except for expected maintenance. In this case the façade cladding and services can be upgraded where necessary, without interfering with the rest of the structure.

The second scenario is the reuse of a panel. When one of the panels becomes obsolete, as different functionality is demanded, it is possible to reuse it in a different supermarket. The panels can be replaced by an option that has got the functionality demanded. As the panels are highly insulated and fulfil all basic functions it's expected the obsolescence won't come through these changes. The changes are expected because the panels need a change in functionality, extra vertical penetrations or skylights can be an example. The panel that came in disuse can be reused without changes in a new Lidl supermarket.

The third scenario is remanufacturing of the panel. When the complete functionality of a panel becomes outdated the possibility exist to break it down to its basic components. Here materials that have reached the end of their technical service life, can be recycled (for the technical cycle) or cascaded (for the biological cycle). The parts that are still performing to their technical expectation can be reused directly in a new application.

1.5 Comparison of results

The three designs each have their positive and negatives. What can we learn from these comparisons?
First the material cycles:

- Original 0% biological feedstock
- Technical redesign 0% biological feedstock
- Green redesign is for 79% biological feedstock

The green design scores the highest on % of mass being in the biological cycle. The load-bearing structure is ignored in this case, otherwise the structure would be for 95% biological due to the heavy weight of the load-bearing structure .

Weight of the roof system :

- Original 15.5kg/m²
- Technical redesign 28,7kg/m²
- Green redesign 24,7kg/m²

Weight of the load-bearing system :

- Original 180kg/m
- Technical redesign 180kg/m
- Green redesign 280kg/m

The original roof has the lowest weight, almost half of the technical redesign, the green redesign turns out with a better score due to the lower weight insulation. For the load-bearing structure of the main sales room, the green redesign is far heavier than its competitors. It might be slightly over dimensioned but due to the 10 times lower Youngs modulus more of the material is needed to fulfil the same task.

MCI of the roof systems :

- Original 0.15
- Technical redesign 0.50
- Green redesign 0.91

The green redesign scores by far the highest on this topic, and this is due to the high recycled feedstock from the ECOBoard and metisse insulation. While it's possible to produce products that use fully recycled feedstock, it doesn't make a change on the total demand for virgin feedstock. The technical redesign also showed a difficulty for finding a lightweight adhesiveless roof system. The sandwich panels currently employed all use steel plates with adhesives on them. Other sandwich systems, especially wooden panels, add a lot of extra weight and costs to the structure.

For the Disassembly Potential the differences were already examined, as shown in the diagram below the redesign greatly improves on the original. Due to the parallel nature of the assembly it's also possible to disassemble each part independently. The Relational Patterns and Connections aren't greatly improved. This due to the roofing membrane in both instances, which envelops the whole structure.

The comparison between the designs show the higher disassembly- and reuse potential comes at a cost. The sandwich system is almost two times as heavy as the original design, the panels become too heavy to be lifted by a single labourer, a crane is needed to place them on-site. The redesigns show a full circular design is almost achievable. It highly depends on establishing the right contracts with your suppliers. The redesigns show that just changing the materials isn't sufficient. The design itself needs to enable the disassembly, on top of that the current building management strategy the Lidl employs needs to change.

6.4. Conclusion

The analysis of the Lidl's specification showed many opportunities and benefits, for adding circularity to the Lidl's supermarket development. The Specification analysis showed, the largest value would be gained by introducing reuse in the Lidl's material management. Many materials become obsolete far before their technical service life is over. To evaluate the possibilities and benefits of adding reuse to the supermarket a redesign is proposed. The roof is chosen for this redesign, as it has a high potential for circularity and provides vital functionalities to the Lidl's design. For the assessment of the Lidl's roof design the Material Circularity Indicator and the Disassembly Potential were applied. Here they were applied on the scale of the complete roof system, instead of the individual materials.

The analysis of the original roof shows the total system is currently linear. The Disassembly Potential and the Material Circularity Indicator both show the reasons for this linearity. The original design makes use of an layered assembly. This assembly is made up from, a corrugated Steel plate, vapour barrier, PIR insulation and a Flexible Polyolefin membrane. The plastics, which make up most of the layers, all receive a very high LFI. When a LFI close to 0 means the system is more circular, when it's closer to 1 the system is linear. The LFI for the plastic ranges between 0.58 and 1, resulting in a total LFI of 0.55 for the roof system, showing the materials themselves are already linear. The resulting MCI receives a score of 0.15 for the whole system, a score close to 0 means the MCI being fully linear and a score close to 1 being fully circular. This low score is caused by premature obsolescence of the materials employed. Most have a technical life of 75 years but are only employed for 20 years, showing most of the value remains within the material.

The Disassembly Potential explains why the materials are mostly demolished instead of reused, the structure isn't designed for disassembly. The roofing system is designed for its lightweight and fast construction. The result is a low score on almost all criteria in the assessment method. The only high score is on the Life-cycle Coordination. The Lidl builds all stores with materials last at least 20 years, even the Disassembly Potential shows the potential for their reuse. The resulting score for the Disassembly Potential is a TC of 0.44, showing that 30% up to 70% will be demolished at the end-of-life.

From this two redesigns are proposed, to examine the possibilities and the steps which have to be taken by the Lidl before they can become a circular supermarket chain. The Technical redesign is the first, it examined how the Lidl could become circular by sticking as much to the original materials and design as possible. The materials used within the original design all have potential to become circular, except for PIR. The chemical compound that makes up PIR makes actual recycling not an economically viable solution. All other materials, in the roof system, have established recycling processes that keep the materials at their highest value, these should just be used. The only material changes made within this design, are the change of insulation material and the roofing membrane material. The insulation is changed from PIR to Rockwool and the membrane from FPO to Derbipure. The method employed to lay down Rockwool is done without overlaps, allowing for full, and continued, reuse at the end-of-life instead of full demolition. The material can be removed as it is sturdier than PIR and the geometry isn't used to stick them together. During renovation the insulation can be removed and employed again on another site or on the same site as it loses no value at all. The MCI was calculated with this reuse in mind, with the reuse of the Rockwool the MCI goes up to 0.52, still linear but already performing better. If the plates aren't reused the MCI is lower than the original roof system, this happens because of the heavy nature of the plates, influencing the equation more. The MCI would, without reuse, end up lower than the original, at 0,11.

The second redesign is the Green redesign. As can be seen within the technical redesign, just the substitution of materials isn't enough, the total assembly has to be changed, material management needs to be introduced to ensure the materials are actually reused. The MCI is a great tool on it's own to examine the circularity, but the DP actually allows the MCI to become circular. While the Material Circularity Indicator isn't able to include biological feedstock yet, it is still important to start including sustainable renewable feedstock. With this in mind the materials were chosen for the design. Accoya® Glulam for the load-bearing functions, ECOBoard for all plate materials and Derbipure as the roofing membrane. The insulation material and the vapour barrier are both still within the technical cycle. On the material market there is a high

variety in insulation materials, enabling choice for the Lidl. The eventual choice fell on Metisse recycled cotton insulation. Though there are biological options they are expensive or difficult to fireproof. Metisse consists for 85% out of recycled feedstock and can be fully recycled into new feedstock at its end-of-life. For the vapour barrier there isn't a biological solution, there isn't much choice for different materials at all, the most used solution are LD-PE plastics. The design was constructed in such a way that all connections are reversible. All major functions are provided through the use of components, these contain the sub-structure, insulation, air-tightness, vertical penetrations, and where necessary sky lighting. The only layer which can't be build in a method which enables disassembly is the roofing membrane. As the membrane needs to be completely watertight all seams need to be either adhered or thermally welded. Whenever a change has to be made to the design the membrane will have to be destroyed. Besides that the TC reflects the reversibility with a score of 0.81 the expectation is that there will be barely any parts which need to be demolished, deconstruction is an economically viable solution

The only requirement is the implementation of a system that makes the reuse possible. The materials have to be stored, the individual technical service life of components need to be known. Parts need to be re-manufactured when obsolete, the Lidl needs to remain close eye on their designs as it all has to be generic, same dimensions and connection principles in the load-bearing structures in all their stores.

The comparison between the designs show the higher disassembly- and reuse potential comes at a cost. The sandwich system is almost two times as heavy as the original design, the panels become to heavy to be lifted by a single labourer, a crane is needed to place them on-site. The redesigns show a full circular design is almost achievable. It highly depends on establishing the right contracts with your suppliers. The redesigns show that just changing the materials isn't sufficient. The design itself needs to enable the disassembly, on top of that the current building management strategy the Lidl employs needs to change.

7 WHICH CHANGES HAVE TO BE MADE TO THE LIDL'S SPECIFICATION ALLOW FOR THE IMPLEMENTATION OF THESE CIRCULAR REDESIGNS?

With the knowledge of the redesign and the assessment methods in mind, the final step is the reimplementation of these into the Specification. The Specification, as contract model, is only one of the many models currently employed. STABU, one of the largest knowledge institutes about classifications, standardisations and specifications in the Dutch building industry (STABU, n.d.), has done research on the use of the standard Specification. Their results show that the standard Specification is losing in interest. The building industry is shifting from the Specification to new types for building contracts, like the building team or integrated contract structures (Design & Build, DBFMO, etcetera.). These kinds of contracts allow the contractors influence the design process and removing part of the influence of the client (Kervel, 2013). While the whole research examined the current Specification used by the Lidl, the Specification is just one of the many possible contract models (Wamelink, 2010). The Lidl's current Specification already prescribes all materials along with their specific supplier, instead of an description of their expectancies of the products used.

7.1. Current sustainability and circularity criteria in the Specification

Within the Specification, the Lidl only demands certifications on sustainability four instances. The Specification codes, which contains wooden materials, all contain a paragraph on the sustainability of the woods harvesting. All wood used in the construction needs to contain one of the following certifications:

- 24.01.01 Al het te leveren hout (cq. houten producten cq. papier cq. drukwerk), zoals vernoemd in hoofdstuk 24 dienen aantoonbaar afkomstig te zijn uit duurzaam beheerd bos. Van aantoonbaar duurzaam beheerd bos is in elk geval sprake indien:
- Het geleverde hout (cq. houten product cq. papier cq. drukwerk) is gecertificeerd met een handelsketencertificaat van PEFC of FSC en
 - De uitvoerder van werken cq. diensten beschikt over het bij behorende PEFC of FSC handelsketencertificaat. (of beiden indien producten van verschillende certificaten worden verwerkt)
 - Andere passende bewijsmiddelen (waaronder deskundigenrapporten) worden overgelegd waaruit genoegzaam blijkt dat wordt voldaan aan aantoonbare afkomst uit duurzaam beheerd bos zoals in internationaal aanvaarde omschrijvingen is bedoeld. In Europa zijn dit de Pan-European Operational Level Guidelines for Sustainable Forest Management zoals erkend door de Ministerial Conference on the Protection of Forest in Europe (Lissabon, 2 tot 4 juni 1998). Buiten Europa zijn dit de UNCED Forest Principles (Rio de Janeiro, 1992) en, waar van toepassing, de richtlijnen uit internationale en regionale initiatieven (ITTO, Montreal Process, Tarapoto Process, UNEP/FAO Dry-Zone Africa Initiative).

The second and third certification, demanded on a few products, is the DUBO- and the C2C certification. This certification is only demanded for the codes shown below. The DUBO certificate ensures a product belongs to the top performers on sustainability, compared to functionally identical materials and products (DUBOkeur, 2014). Here in lies a focus on emissions and toxicity. Within the Lidl's Specification there is only a demand for it three times. While the Cradle2cradle aims to grade materials on their Circular performance, this one is only demanded once:

22.02 Kalkzandsteen, vuilwerk

22.02.01 Algemeen:
Oppervlakcriteria overeenkomstig met de uitgave van het Bedrijfschap Afbouw/tba, Oppervlaktebeoordelingscriteria metselwerk groep 5.

Lijmwerk moet zijn aangebracht door een bedrijf dat het KOMO-procescertificaat voert overeenkomstig BRL 2826+w08.

De lijmblokken rondom vol en zat verlijmen, de naden moeten glad zijn afgestroken.

22.02.02 Kalkzandsteen lijmblok

Detail:	FIL_PL01A FIL_DS01
---------	-----------------------

Keurmerk: Voorzien van **DUBO**keur of C2C Silver certificaat;

33.05 Kunststof dakbedekkingssysteem, mechanisch bevestigd

33.05.01 Dakbaan:
- Overlap (mm): minimaal 120;
- Naden gelast d.m.v. hete lucht met lasautomaat.
Mechanische bevestiging
- aantal en positie volgens berekening aannemer, conform NEN-EN 1990 en SBR 239.
- bevestiging d.m.v. ~~Sarnafil SB-schroeven met Sarnafil KTL~~ Sarnafast SFT 50 x L ronde tule + SBF 6,0 x L carbon coated bevestigiger ~~ovale drukverdeelplaatjes~~. Schroeven mogen maximaal 30mm door de dakplaat heen steken. Drukverdeelplaatjes geheel verdekt in de overlap verwerken.
- kinnen mechanisch bevestigen met Sarnabar 6/15 + krachtend verdelend lassnoer FPO 4 mm.

33.05.02 Kunststof dakbaan
Fabrikaat: Sika AG.
Type: Sarnafil TS 77-20 (TG 66-20 voor de randen e.d.)
Duurzaamheidscentrifisering: **DUBO**keur;
Kleur: Conform afwerklijst.

37.03 Hardschuim

37.03.01 Isobouw EPS klikvloerplaat

Omschrijving : Naadloze vloerisolatieplaten van geëxpandeerd polystyreen;
Isolatiemateriaal : Brandvertragend gemodificeerd geëxpandeerd polystyreen;

Randafwerking : Zelfzoekende randafwerking met klik-verbinding;
Warmteweerstand: Conform 37.01.01;
Druksterkte (kPa) : Conform constructeur, minimaal EPS 200-SE;
Kwaliteitscertificaat : KOMO productcertificaat;

Milieucertificaat : **DUBO**keur

Besides the certification of woody materials, another certification is demanded on sustainability, it's the energy label which needs to be at least A++++. This is specified among the required measurements, along with airtightness.

00.04.01 **Energielabel nieuwbouwfilielen A++++**
Nieuwbouw filialen dienen te worden voorzien van energielabel A++++. Voor het verkrijgen van een energielabel zal gedurende het gehele bouwproces bewijslast moeten worden verzameld door de aannemer. Tijdens de eerste bouwvergadering wordt door Lidl het projectdossier Energielabel overhandigd waarin staat omschreven welke zaken verzameld of vastgelegd moeten worden.

Tijdens de bouwkundige oplevering zal er door Buildinglabel (Grootzeil 1 3891KH Zeewolde, 036-5220042) een visuele controle worden uitgevoerd. Deze controle wordt betaald door Lidl.

These four certifications aren't enough to enforce circularity within the design and construction. As a Specification writer you are allowed to add anything to it. The format provided by the STABU is just a format, a recommendation, not a rule (Lousberg, 2018). This can be seen as the principles of the Circular Economy demand a more regulation than with just these two demands. The demand for more sustainable certification requirements in the Specification has already been addressed years ago by state secretary D.K.J. Tommel. He asked for DUBO-certifications to be added to the STABU standard Specification. According to the director of STABU at that time M.L.A.M. Hezik the important choices on sustainable building should be incorporated into the designs and drawings and not in the Specification (n.d., 1995). The DUBO-certifications aren't an inherent part of the Specification, NIBE attempts to influence material choice through their classifications. By adding Nibe's environment classifications they want to guide contractors to more sustainable solutions with a smaller environmental impact on our planet (NIBE, 2018(1)). They advocate for the addition of code '02. NIBE'S MILIEUCLASSIFICATIES' to the Specification. The following should be added according to NIBE (NIBE, 2018(2)):

“00.02.17 Verwerking van bouwstoffen

02. NIBE'S MILIEUCLASSIFICATIES

De te leveren bouwstoffen ten behoeve van de uitvoering van het werk en voor zover deze in het werk achterblijven, dienen te voldoen aan klasse 1, 2 of 3 van de NIBE's Milieuclassificaties. Indien een bouwstof wordt gekozen welke uit een andere milieuklasse afkomstig is, dan dient deze keuze gemotiveerd te worden. De NIBE's Milieuclassificaties zijn gepubliceerd op de website www.nibe.info.“

While the classifications provide a great insight in the environmental impact of the materials, they don't provide a score on their circularity. The Specification provides an opportunity for an addition on the grades. When examining the law that describes the building materials, a few interesting points jump out, of which also the NIBE's code makes use. The UAV 2012 described in chapter seven, paragraph 17, that demands about the materials made by the client need to be followed to the letter by the contractor. The contractor is allowed to propose comparable building materials, as long as the client agrees (Spies & Verhagen, 2012).

Only for 1 material in the Specification the demand is made for a NIBE grading or an environment classification.

33.05.02 Kunststof dakbaan
Fabrikaat: Sika AG.
Type: Sarnafil TS 77-20 (TG 66-20 voor de randen e.d.)
Duurzaamheidscentrificering: **DUBO**keur,
Kleur: Conform afwerklijst.

Materiaal: Kunststof / FPO-dakbedekking (PVC-vrij).
- Dikte min. (mm): 2.0;
- Dakmembraam **polyester weefsel en glasvezel versterkt**;
Begaanbaarheid (BRL1511/01-93): Klasse R3.

Milieuklasse:

- DCBA-methode (Bureau Boom): klasse B;
 - TWIN model (NiBe): Milieuklasse 1a gezondheidsbeoordeling: neutraal.
- *Op alle platte daken*
- *Op alle hellende daken (alternatief)*

A clause for the highest value cycle, reuse, is already present in the Lidl's specification. These criteria only come into view when a product becomes obsolete, reaches the end of its technical service life. The Lidl can employ this clause to save components from demolition, this clause should be used to add components to a new site to be reused.

10.04 Te hergebruiken onderdelen

10.04.01 De volgende onderdelen worden uit het werk verwijderd en opgeslagen voor eventueel hergebruik:
- (in te vullen door de architect)
-

7.2. Adding circular criteria

The previous paragraph shows the possibilities for adding criteria and indicators to the Specification already exists. This also provides room to add the MCI. Though adding the MCI directly proves to be more difficult than would be expected. The Circular Economy has two major cycles, the Technical - and the Biological cycle. Adding the MCI would only represent the Technical cycle, this would ignore a large part of the Circular Economy (Ellen Macarthur Foundation & Granta Design, 2015b).

Under code 00 of the Specification, the 'Bepalingen en Voorwaarden' are described, it describes all basic information of the project, in the Lidl's case it contains the steel grade for the connectors and the measurements. The suggestion would be to add a code on the MCI, the definitions are taken from the report with slight alterations and additions (Ellen Macarthur Foundation & Granta Design, 2015b):

00.05 Material Circularity Criteria

00.05.01 Bill of Materials

A Bill of Materials is kept by the contractor and handed over to the Lidl before the construction commences, it should contain all parts and components that are required to build the product. For each of the components the precise type and amount of materials is listed. It contains the percentages for the source of the feedstock (virgin, recycled or reused) and the end-of-life scenario (reused, remanufactured, recycled, composted, incinerated or wasted), along with the cycle (Technical or Biological) to which the material belongs and their life-cycle.

00.05.02 Technical- or Biological Cycle

Materials from the technical and biological cycle should be kept in their own cycle, if combined in a product they should be separable back into the basic materials.

- Biological materials will be kept non-toxic during the building process, biological waste materials will be composted and returned to the biosphere.
- Technical materials will be kept separate and are sorted on the building site. Waste will be returned to the supplier.

00.05.03 Feedstock circularity

Technical materials can only be used if they have a potential 100% recycled feedstock. Biological materials can only be considered circular, if the specific resource renews faster in nature than it is harvested.

00.05.04 End-of-life

Components used should be fully separable back to the independent materials used within them. Materials from the Technical cycle need an end-of-life scenario of: reuse, remanufacturing and/or recycling. There must be at least one certified recycling plant for the materials used or the supplier must take back the material to reintroduce it in its production process. The efficiency of the recycling process of the materials needs to be 100%.

Materials from the Biological cycle used in the construction must be kept non-toxic. The end-of-life scenario needs to be: for high value biological material cascaded use in another application, low value biological materials can be composted.

00.05.05 Comparable products

The contractor is allowed to suggest comparable materials, elements, components or systems to the Lidl with a written explanation, as long as they fulfil the above specified criteria. The Lidl has the right to deny these suggestions. If a suggestion is approved it must be added to the Bill of Materials along with all the criteria.

The Material Circularity Indicator itself isn't used within the addition to the Specification. The MCI currently doesn't provide full coverage for all materials and isn't a widespread indicator yet. The important aspects of it are contained within the text above. These criteria described above are not possible with the current Specification, as the redesign only covers the roof, all materials and systems have to be redesigned before the Specification is fully circular. There is still room for improvement for the foundation and flooring used. The Material Circularity Indicator itself needs some improvements, before it can be fully used in the Specification. It currently only describes the Technical side of the Circular Economy and completely ignores emissions. It's just a small window into the aspects which give strength to the Circular Economy. Still the above described aspects can be applied to circular chapters in the Specification.

The Disassembly Potential is less straight forward to add in the Specification. The Disassembly Potential relies heavily on the design. It provides insights in the do's and don't during the construction. The greatest impact it has on the Specification is the removal of adhesives. Which would only be possible after a complete redesign of the foundation, floors and walls. The piping can already be installed mechanically and the adhesives should be remove from those codes. As much as possible should the same type of connectors be used. This will ease the disassembly and not many tools will be needed.

7.3. Redesign non-circularity

There are many materials and assembly sequences currently employed in the Specification that hinder a circular approach. These provide opportunities to reinvent the Lidl, as the circular supermarket chain. The redesigns proposed in the previous chapter provide insights on how to approach the issue. In the Specification analysis chapter, the non-circular parts from the Specification were highlighted. Each of these codes has a chance to become fully circular.

As a supermarket you're constantly changing due to the fluctuating demands from the public(LIDL, personal communication, 30-03-18), more cooling, more ovens, open space, natural light, no light, et cetera. By using long lasting and rigid materials the functional changes can only happen through renovations or demolitions. When using materials which last for more than 75 years, for functions that last 8 or 20 years, you're losing out on at least 55 years of value. This also applies to façade materials, the metal façades last at least 40 years, with a potential to last far longer.

7.4. From linear to circular, the development strategy

There are a multitude of reasons for the Lidl to employ the Circular Economy. A few of them are outlined within chapter 2. Three principles can be distinguished, reduction of waste, keeping materials at their highest value and regenerate natural systems. Each has direct and indirect benefits on the general idea of sustainability. The Lidl approached the TU Delft during the first month of 2017 with the question: How can we make our building stock and operational processes circular?(Lidl, personal communication, 20-3-2018) The preliminary study, found in appendix (Preliminary Research), shows that the Lidl has got an extensive portfolio of supermarkets. With over 10.000 supermarkets worldwide and over 415 in the Netherlands it already shows opportunities for circularity. The Lidl is responsible for their own real estate and is the owner of this real estate as well(LIDL, Personal communication 20-03-18).

7.4.1. Current Lidl building development strategy

This sub-chapter is based mostly on direct communication with the Lidl. With over 415 stores (Distrifood, 2018) in the Netherlands already, and plans to go to 500 in the upcoming 10 years (Lidl, personal communication, 08-06-18). Each of these supermarkets has a considerable footprint and material usage. Due to the fast changing demands, the supermarket renovates the internal Space plan of the stores every 8 years. These changes happen as consumer needs change, consumers want more fresh baked bread so more ovens are introduced, fresh grown products are in higher demand, both these result in a higher cooling load. Each of these demands has an impact of the energy demand of a supermarket, and with it an impact on the floor plan. The supermarket as a whole(Space Plan, Services and Skin), is renovated every 20 years on average. For a building stock of the Lidl's size this means they have to renovate over 20 supermarket each year. On top of that the Lidl demolishes and builds around 5 supermarkets each year (Lidl, personal communication, 08-06-2018). The general approach of demolition is to find a contractor to do this for you. The materials, for which there is no predetermined recycling contract with the supplier, become the property of the contractor. The contractor can dispose of them as he sees fit. This results in a vague end-of-life scenario for the products, products for which the contractor doesn't see much value will be send to a recycling plant. Within the building cycle, the design and the operation of the supermarket are done by the Lidl. Construction and demolition are done by a third party. The result of this strategy can be seen in the diagram on the left.

As could be seen within the analysis of the Lidl's Specification, the Lidl as a chain loses out on a lot of value on their building materials used. For many materials they only use 30% of the products technical service life, for the materials used inside often just 10% of the materials service life, discarding and demolishing products before they become obsolete. This premature obsolescence is caused both by not knowing the inherit value left in the materials, but also through the design that relies on demolition instead of deconstruction. In the analysis of the original roof, chapter 6, it is shown that the design of the current roof structure results in a design which is easy and quick to assemble, but time consuming to disassemble. The result is a structure with a high potential for demolition.

On a multitude of fronts structural changes have to be made, if the Lidl wants to become a fully circular supermarket. While these changes might have an higher cost to setup, in the long run they will result in cost reductions for the Lidl. The building industry is slow moving compared to all other industries, most buildings around us will be there for the next 60 to 90 years(Pomponi & Moncaster, 2016). Even for a fast changing function like retail, the first changes will become notable after 8 years, during the small renovation. The biggest impact will be seen after 20 years, when the large scale renovations take place or when a new supermarket is built.

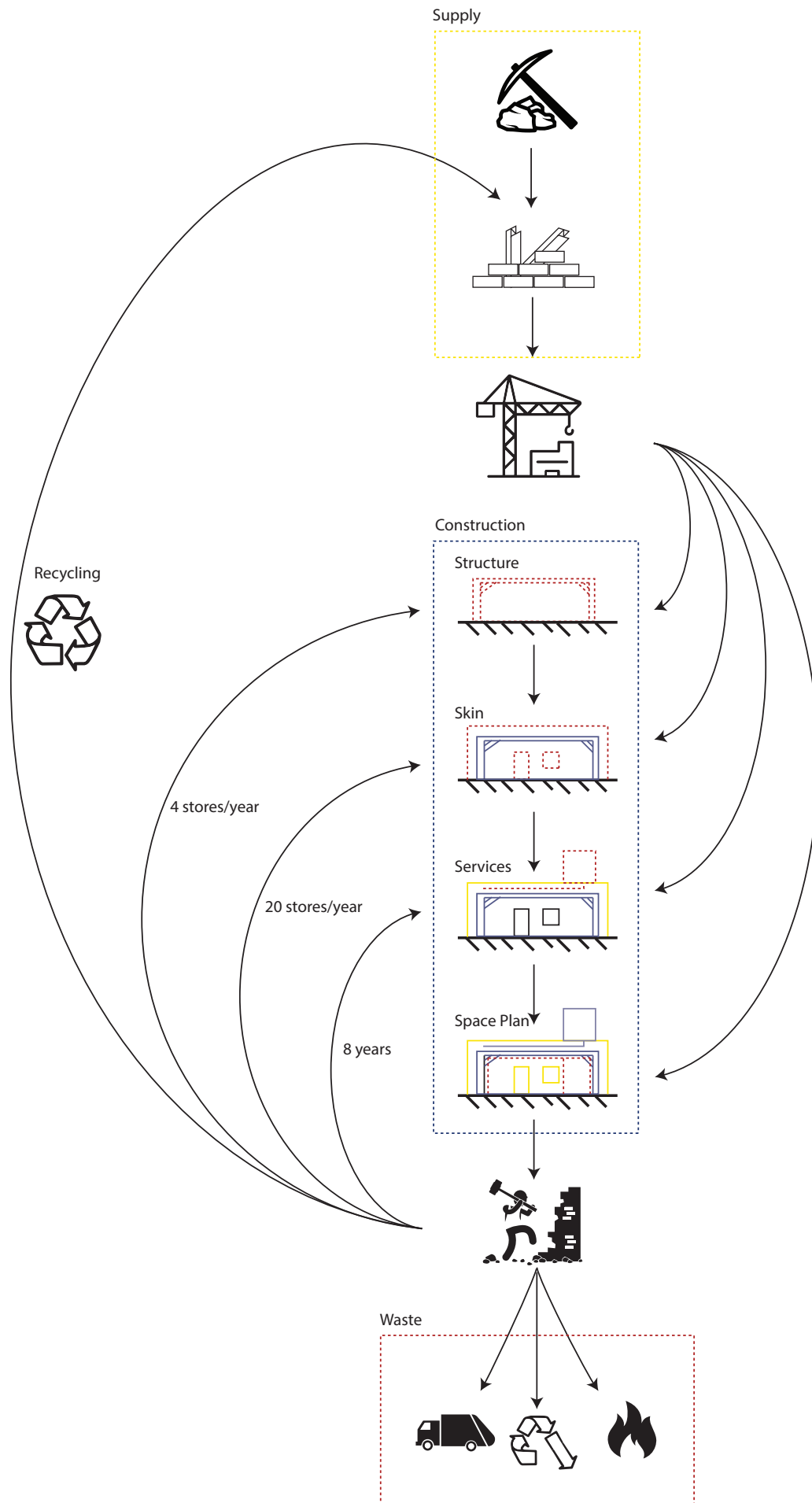


Fig. 101 : Lidl's current supermarket development strategy (source: own image)

7.4.2. The Circular supermarket building cycle.

The changes required to make the Lidl's building stock circular can be divided into a multitude of steps. For each of these steps, the impact will be noticeable over a different time period. Each of these will help the supermarkets building strategy change from a linear to a more circular one. The first step contains the changes for which the impact can be seen straight away. The second step are the changes for which the result will be visible after 8 years, during the first renovation. The third step are the longer term changes, for which the results won't be seen for the next 20 years. The fourth step are the changes which require a time span longer than 50 years before they are completely implemented. Each of these changes can be related to part of the Specification or the proposed redesigns.

7.4.3. Step one

For the first step the circularity will only be examined for the building stock and designs, which are currently employed. With over 415 stores in the Netherlands, the Lidl's expects to renovate 20 stores each year. On top of that each year four stores are completely demolished and around 5 are built new(Lidl, Personal communication, 08-06-18). The Specification analysis shows that in each of the renovated stores, components and elements will be present, which still contain most of their technical service life, in other words their value. Many of the Lidl's structures contain standard building materials. Almost all stores have the same façade cladding, window frames and drop ceiling. These are the parts which got a sufficient score in the analysis, or a partially sufficient.

First all the elements would need to be assessed on their current technical performance and if they are still up to par. The second step would be to find storage for the components and elements which still have most of their technical service life left. The last criteria required would be for the designer and contractor for the new supermarket to know these materials are available and use them in a new design. The result of the changes would be visible almost immediately. The materials, which are used as an example here, are all chosen on their Disassembly Potential. All these elements easy to reach, they are the most outer finishing layers. Each of these is assembled by using direct connections, screws, bolts or rivets.



Fig. 102 Fig. 53: Drop ceiling, Lidl multatuliweg Delft (source: own image)



Fig. 103 Fig. 54: Drop ceiling, Lidl Doctor H.J. van Mooklaan Rijswijk (source: own image)

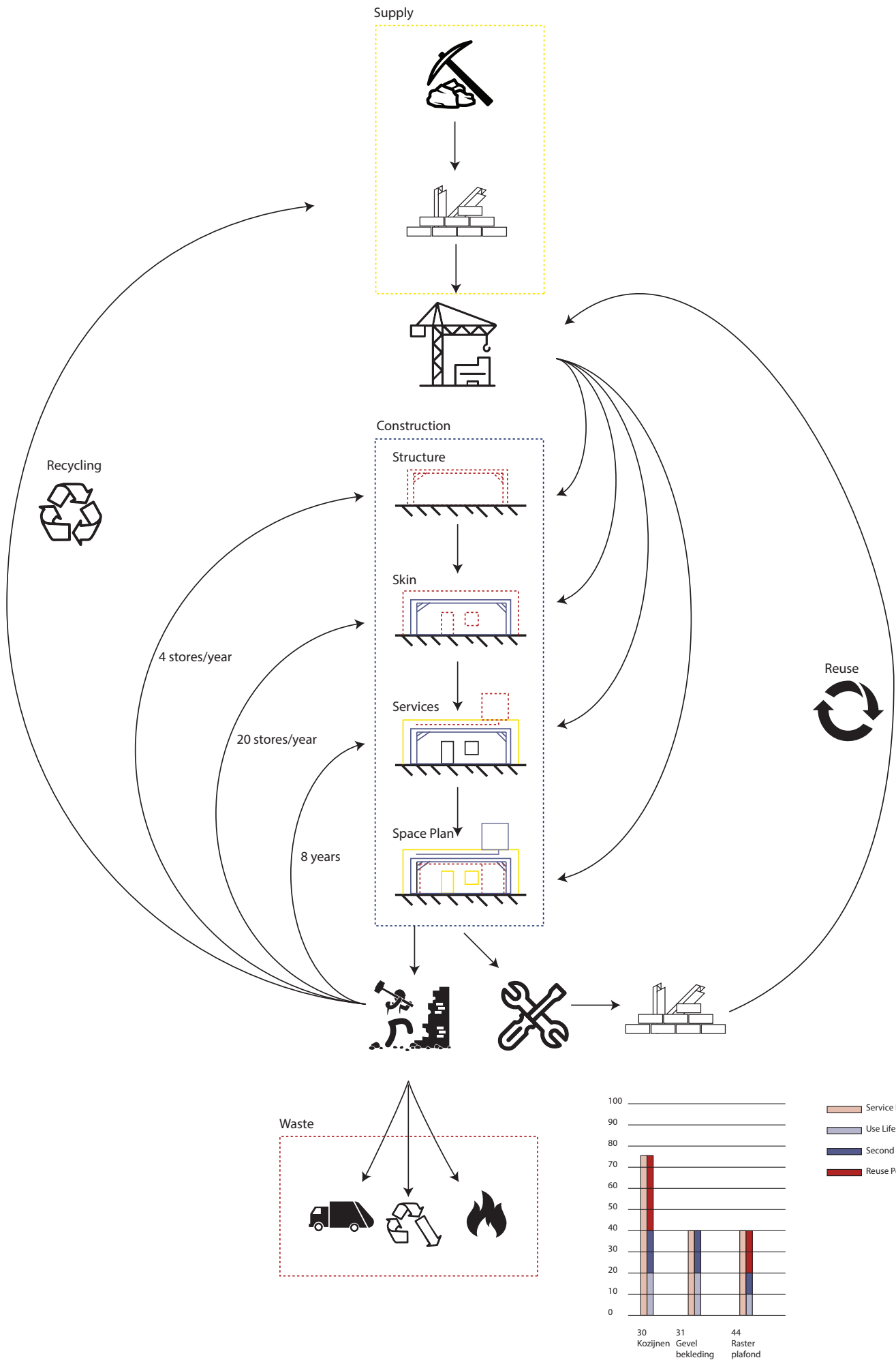


Fig. 104 : Lidl step 1 in the circular development strategy (source: own image)

With this first step the foundation is laid for more radical changes in the upcoming tiers. Material storage has to be introduced, a database has to be kept on what's in stock and the contractors have to be instructed to build for deconstruction instead of demolition. In the figure below the result can be seen for the materials. All materials will have to be examined during deconstruction. For example, the aluminium façade cladding has a predicted technical service life span of 40 years, aluminium is known to last almost indefinitely when it is maintained properly. The window frames and the ceilings can fully finish their service lifespan. These can even be reused a third or fourth time after this. This would eliminate part of the construction waste, along with a saving for the Lidl as there isn't a new investment needed for new materials. This would lower the constructions costs. Not all components used in the cladding and façade that can be reused have fall in the Circular Economy. The PIR-sandwich panels can't be recycled, enhancing their useful lifespan ensures their inevitable environmental footprint gets spread over a longer period, reducing the overall impact. This way a new energy and carbon investment for a cladding is avoided.

7.4.4. Step two

The second step are the changes for which the circularity will be noticeable within 8 years. These changes have to be made for the Space Plan of the supermarket. In the analysis of the Specification it is noticeable how long lasting materials are used for short functions. Indoor masonry and timber framing, which both last over 75 years, are used for an 8 year function. These parts require a complete redesign and re-materialisation. In their current state they can't be reused easily. The sand-lime bricks are all adhered together, through the use of glue. The only option for removing the bricks is by demolition. For the timber frame the possibility for deconstruction exists, though most of the parts get nailed together, resulting in damage during disassembly. The walls are covered by a tile layer, making disassembly even more difficult as mechanical connections become unreachable. This shows the difficulty of reusing the existing dividing wall systems.

This part requires a complete redesign, new materials and new connections. The redesigns don't have to be anything new. There are a multitude of options, which can already be described as circular. For example the use of metal stud walls as a technical solution, or timber stud walls which stay within the biological cycle. Both can be deconstructed instead of demolished and reused somewhere else (NBD Cobouw, 2016). This change could be made almost immediately as both systems have been around for years. This would allow the Lidl to extract full value out of the dividing walls, instead of only making use of the functional life. With the right deals with the suppliers, the Lidl could almost completely eliminate waste from their Space plan. Materials can be chosen that have a fully established recycling method.

During the renovation, the walls can be stored within the store themselves if there is still use for them. If there is no use they can be send to the Lidl's general storage, which would be established by step 1. This is the first step for which one of the largest principles is added for enabling circularity in the Lidl's design, it's also the largest recommendation from the Technical redesign proposed in chapter 6:

Make the design generic.

This single principle ensures parts can be used all throughout the Dutch Lidl supermarkets. For the walls this would mean, standard sizes, standard connections and standard functional layering. This already happens to a degree, as the wall structure is standardized, but the connections are not reversible, making reuse difficult.

The implementation of these walls could be done on any site that needs an upgrade on their Space plan. The results for the longevity of these walls won't be noted until first renovation, which will be after 8 years. After that the return of the investment on the materials will become noticeable. Well implemented deconstructable elements would allow the functionality of the store to be updated more often. With only requiring a small labour investment, the walls can be demounted and reconstructed in a different floor plan, reducing the overall costs over the years, even allowing functionality to change every five years.

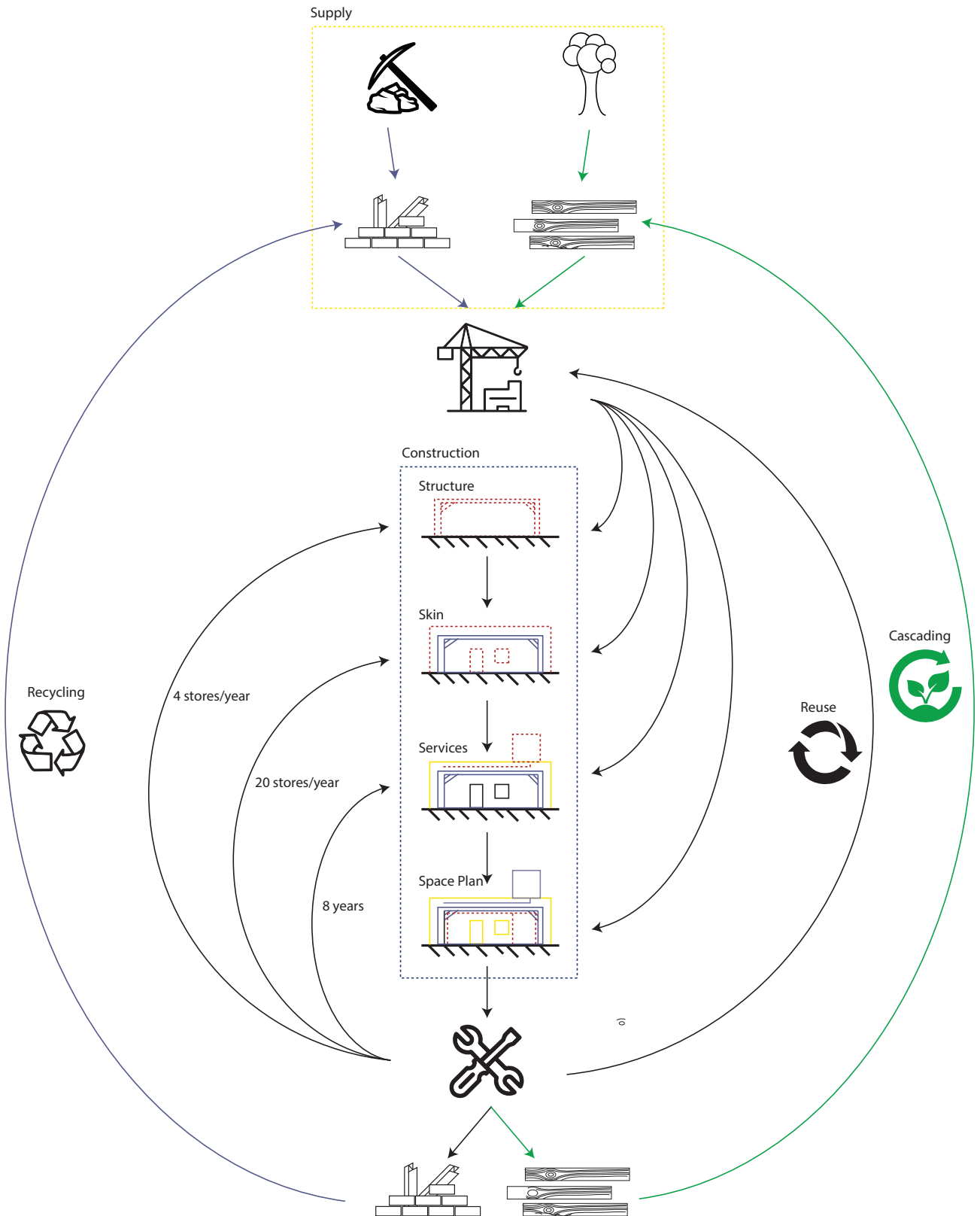


Fig. 105: Lidl step 2 in the circular development strategy, introduction of the biological cycle and elimination of waste.

7.4.5. Step three

The third step would be the fully circular supermarket, this requires a long term commitment and a while for the return on investment. This step includes all layers of the Steward Brand model which weren't yet included, Structure, Skin, Service and Space plan. The step relies on the new build supermarket structures and on the large scale renovations which happen every 20 years. For the new build supermarkets the full circular design is introduced, with a focus on reuse. In the large scale renovations Skin, Services, and Space Plan are all changed to circular systems. The Structure can only be applied to a new supermarket, resulting in the slowest implementation of all layers. The products used by the Lidl in the current Skin layer, are not from a circular origin and are difficult to disassemble. The labour required to take down the elements in one piece make the value gained, from an economic standpoint neglectable (Dantata, Touran, & Wang, 2004). The system asks for an overhaul for the employed construction methods, this also applies to load-bearing structure. This third level will be easier to implement in future designs than for current designs. The current designs from the Lidl employ a multitude of different dimensions and connections, making standardized prefabrication of elements difficult. Panels applied to one façade can be deconstructed and reused at another site, or remanufactured if there is no need for the specific type at all. It would suddenly allow the materials from all three layers to be used to their fullest extent, instead of the first 30% of their technical life. Structures can already be made almost completely circular, when new materials are developed with lower carbon footprints or within the biodegradable cycle, their counterparts in the current structure can be slowly phased out.

This third level requires a view on your future supermarket development and patience. While the first two levels could be employed almost straight away and would take 8 years to show their results, the Third level requires at least 20 years before it will show an return on investment. This investment can be between one-and-a-half or two times as high for the materials required. At the first major renovation this investment starts to become profitable as no new materials are needed until the products have reached the end of their technical lifespan. Until the products have fulfilled their full technical life span, the Lidl can partially sustain itself with its own building waste.

The sandwich panels, which were introduced in the green design, have a service lifespan up to 75 years. After that an assessment has to be made if they can be used longer. This allows the Lidl to make changes to a supermarket, adding skylights or extra vertical penetrations in the roof, without having to destroy all layers in the roof. Instead a panel can be demounted and changed for one that does fulfil the functions required. The sandwich panel can be stored and be used in a new supermarket.

The circularity of the load-bearing structure will take a while before it is noticeable. The structure is the slowest changing layer within the supermarket. The structure of buildings stands from 30 year up to 300 years (Brand, 1994). The structure introduced by the green redesign would have a technical service life of at least 50 years in an indoor application (Hess, n.d.). If the supermarket gets deconstructed at an earlier time the beams can completely be reused on another site. Within the design only 5 different lengths of laminated timber are used. This makes the construction easy to be used on another location. No mistakes can be made on the application as each of the specific components in the structure has its own beam. Columns have three lengths, the main beams only have two varieties, the base elements which connects the beams to each other and the roof system to the load-bearing are all the same size too. The connections are made up from two types in the load-bearing structure. Hinging beam connections and the connections between the Base Element and the main beams. They can be easily distinguished by their size.

Wherever possible, the materials should be tried to be taken out of the biological cycle as much as possible. Not all building materials have a biological equivalent yet. Instead of relying on the technical material cycle the whole supermarket could be constructed from materials in the biological cycle. This is currently only partially possible, as not every material has a biological counterpart, glass and vapour barriers are an example in this area. For many materials there is only a single biological option available, engineered wood has only Accoya® glulam as an option (Hess, n.d.). Derbipure is the only biological option for a roofing membrane. New structures can be constructed with almost fully biodegradable load-bearing structures. There are multiple benefits for biological structures, one of the major ones is the building as carbon storage, as all the carbon the wood consumed during its growth isn't released back into nature as long as the wood is in use. Building structures stand somewhere between 30 and 50 years, the carbon would be stored for that time (Buchanan & Levine, 1999). Partitioning also already has biodegradable potential with timber stud walls (NBD Cobouw, 2016). Even the skin can be made almost completely biodegradable, timber framing, natural insulation materials and natural façade cladding can already be found. The transition to fully biodegradable structures will take a while, just as the transition to fully circular supermarkets.

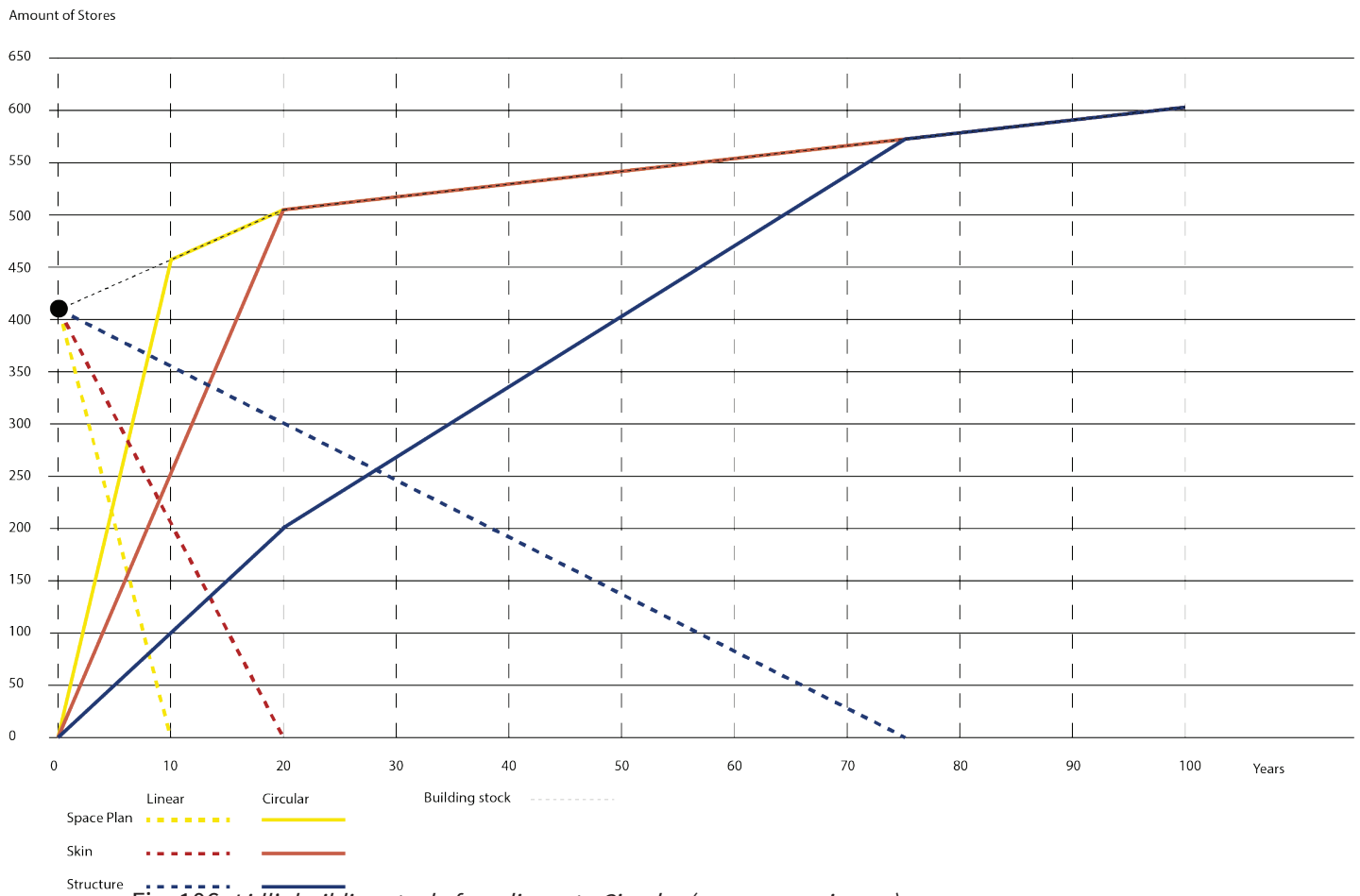


Fig. 106: Lidl's building stock, from linear to Circular (source: own image)

7.4.6. Step four

The fourth step would need a collaboration between the departments of the Lidl in different countries. With over 10.000 stores world wide there is a huge potential for reuse. With a major renovation every 20 years this would result in 500 stores being renovated every year all around the globe. This large scale collaboration would require more countries to participate in the Circular Economy. The surrounding European countries, Germany and Belgium for example, would provide the easiest adaptation. As they have a comparable climate, energy demands will be comparable. It wouldn't speed up the change to a circular supermarket chain, but it would reduce the amount of time a building element has to sit in storage, increasing its use intensity and lowering the amount of storage needed.

7.5. Conclusion

While it is possible to add your own criteria to the Specification, it's difficult to describe them in an understandable manner. The criteria aren't necessarily for the contractors, they are for the suppliers. The deals should be made directly with the suppliers. If the Lidl wants to employ circularity at its highest level, it should focus on reuse instead of demolition. The end-of-life scenario should only be employed at the end-of-life of a material, when its technical service life is over instead of when it's functional life span is over.. Still the materials used by the Lidl need to be circular, even at their end-of-life. Cradle to Cradle has already shown it's possible to add circularity to a Specification. Many other sustainability certifications also found their place in the Specification. It's difficult to determine if the Specification is the best method, as it is just one of many contract forms. The Specification is slowly ending up in disuse. The Material Circularity Indicator would be an interesting way to enforce and ensure circularity during the realisation phase of the project, making sure there actually is a circular end-of-life option. On one hand, it provides boundaries and will it narrow the materials available, though the Lidl already does that by specifying the current materials they use. If the Lidl prescribes all components, it'll also provide a source of value, slightly more expensive elements and components which can be used far longer than the currently employed construction materials. The changes that have to be made to the Specification and the design would be as followed:

- Adding Material Circularity Criteria to the Specification, not the indicator itself.
- Redesign systems that use linear materials (floor, ceiling, interior finishing, partitioning walls).
- Redesign connections and assembly methods that can't be deconstructed into reversible constructions.
- Employ the clause on reuse, which is present under code 10.04.

The changes of the specification would only be part of the solution. A different view on management is needed as well. The current strategy employed is established from a linear point of view, where the Lidl sees themselves as consumer of the building. Through four steps the Lidl should be able to transform their building stock into a circular portfolio:

1. Reuse building elements that can be disassembled, facade cladding, window frames, load-bearing structure, should all be cycled until their inherent value has been used up. This will be noticeable and applicable straight away.
2. Make the Space Plan circular, by using deconstructable wall systems, like the wooden stud wall, the Lidl can reuse their partitioning systems. The return of investment would take at least eight years.
3. Make the Structure, Skin and Services reusable. Higher initial investment will result in lower material costs over time. The impact of a circular choice for the skin would only be visible after 20 years, during the first major renovation. The structure will take even longer, by using biological materials the structure will function as a carbon storage over that period.
4. Collaborate with neighbouring countries, with a building stock of over 10.000 stores world wide there is always a possibility for reuse, reducing the time a part will spend in storage.

Wherever a renewable biological solution would perform just as well as a similar product from the technical cycle, the biological material should be chosen.

8 CONCLUSION AND DISCUSSION

8.1. Research conclusion

Which changes have to be made to make the Lidl's Specification circular, with an emphasis on materials and assembly?

This research focussed on the changes which would have to be made to the Lidl's Specification to make it circular. According to the Ellen MacArthur Foundation the three principles of the Circular Economy need to be implemented before it can be fully classed as circular. These principles are described in chapter 2. There it is outlined that adding them to the built environment is a more difficult case. A building is made up from many different materials, elements and components, each with its own technical and functional life span. The buildings life span is longer than any other product, buildings which are currently constructed probably be around for 60 to 90 years.

The Specification exists in an interesting place, it is the step between design and reality. It contains all materials, elements and components which will be used in the actual building. It contains all the connections and certifications, everything with which the contractor would be able to make the design reality and ensure sustainability or the validity of the products used. All individual parts used in the Specification can be taken apart and examined against the circular principles. These principles alone aren't enough to determine if a design is circular, with these principles you can't compare two designs on their circularity either. An assessment method on circularity must be added to the Specification, to be able to compare materials and designs.

Research shows there are five criteria which should be measured and stimulated by the assessment method:

- Reducing the input and use of natural resources.
- Reducing emission levels.
- Reducing valuable material losses.
- Increasing share of renewable and recyclable resources.
- Increasing the value durability of products.

Currently there are no assessment methods which actually measure all five criteria. As discussed in chapter 4, there are three methods which come close to fulfilling the demand. The LifeCycle Analysis, Material Circularity Indicator and Disassembly Potential. While both the LCA and MCI cover four out of five criteria in their assessment, they at least give an assessment. The DP influences all five criteria indirectly, it measures the chance for disassembly instead of demolition. The combination of DP and MCI provide the best overall view at the moment. LCA does provide insight in the reduction of the emission levels, but examines a product in a multitude of scenarios. The MCI provides an insight in the flow of materials and directly provides incentive to pick materials which can be reused and recycled. This choice of assessment method leaves a gap in the knowledge. The MCI in DP don't cover the emission levels, neither do they show the impact of choosing materials of the biological cycle. They provide data on the material usage of the technological cycle however.

These assessment methods provide the basis for which the analysis of the current Specification can be done. The Specification was analysed with these two assessment methods in mind. The analysis shows two problems within the current Specification on circularity, which have to be addressed before the Specification can become circular:

- Many materials used are inherently not circular, there is no economical way to recycle them at their end-of-life.
- The design used favours demolition instead of deconstruction, resulting in premature destruction of products.

These two problems result in five changes which have to happen, these five changes are addressed in chapter 6 and 7. Redesigns were used to test the assessment methods and examine their limits. Two redesign were made from the original, the Technical redesign, this focussed just on implementing circular materials in the design, and the first steps towards a circular construction. It showed that just using circular materials isn't enough to create actual circularity. The construction principles used in the building needs to enable it as well along with a supporting management strategy around it. The second is the green redesign, this redesigned both materials and construction principles and shows the impact of the redesign of the assembly as well as the materials, it shows that both are needed to become circular. It also shows a current opportunity in the market to introduce circular building materials. For a few building materials there is no option which results in a material with a circular end-of-life scenario, many other building materials in Europe currently have just one circular solution.

From this chapter three changes emerge which have to be implemented to become circular:

1. Exchange non-circular materials, materials which can't be economically recycled at the end of their technical life span, for materials which can be recycled.
2. Enable reuse of materials, by removing static constructions methods, making all connections reversible.
3. Make dimensions and connections generic.

In chapter 7 two more changes are added, for which one has to be implemented in the Specification itself:

4. Implement the criteria from the Material Circularity Indicator to the Specification for circular materials.
5. The development Strategy of the Lidl needs to be changed, reusing elements and components instead of employing new ones.

A large part of the circularity in the Specification still can't be examined through these assessment methods. There is no conclusive method to measure the impact of biological materials, no conclusive method to assess emissions either. With the assessments that are currently available we are able to draw the first conclusions. With this the Lidl is able to start discussions with suppliers, to examine the possibilities and fully map out circular building product cycles. Implementing the changes described above would be a first step towards circularity and open the doors for further implementation of full circularity.

8.2. Discussion

This research shows that the Lidl could start with the first steps of becoming circular, with the changes to the Specification proposed in this paper. Though it also shows that just changes to the Specification wouldn't be enough, changes to the overall design and the current development strategy are required as well.

This research also shows that full implementation of the Circular Economy is difficult at the moment. There is a gap in the knowledge currently available on circularity. The gaps in knowledge especially show when examining assessment methods of circularity.

Assessment criteria

The two methods employed to assess circularity of the Specification in this research, are the Material Circularity Indicator and the Disassembly Potential. The MCI gives an insight in the consequences of a material choice. The DP provides an insight into the consequences of a design choice, the DP doesn't measure any of the circular assessment criteria directly. The combination results in a decent prediction on the Reuse potential and the end-of-life scenario of your product. However these two only measure one of the two main cycles in the Circular Economy. The methods are only able to assess the impact of a material choice in the Technical cycle. The Biological cycle isn't included in the formulas yet. This makes the comparison between materials from this cycle difficult, as the end-of-life scenarios established in the Technical cycle are not directly applicable to the Biological cycle. Biological material are difficult to recycle, they can only be cascaded and eventually composted. The assessment methods don't provide knowledge about the emissions produced either. When two materials would be considered fully circular, a distinction could be made on the different environmental impact of a material. The addition of the LCA to the assessment method would seem like a solution, especially since it's the most in depth method currently available on the emissions. This method however requires an enormous amount of data, making it difficult to employ it yourself, especially because an assessment is needed for each individual supplier and project location. The inclusion would seem to provide all data needed, but the LCA is made to analyse products from cradle to grave, it is an inherently linear approach. Even with the addition of the LCA, no fully conclusive choice can be made between materials. This shows an opportunity for further research into the circular emission assessment method.

A small material market for circularity

Even with the assessment method, it is difficult to find fully circular building products. The products which did acquire a Cradle to Cradle certification reflect this. The Cradle to Cradle certificate gives an insight in how well the product performs to circular criteria, currently there are no products which receive the platinum status, or in other words, are fully circular (Cradle to Cradle, n.d.). There are many materials which have the potential to become fully circular, but they won't be for the upcoming years. Steel is a great example, it is one of the most recycled materials on our planet (Graedel et al., 2011). The material is 100% efficient in its recycling process and over 95% of the steel waste is recycled. New steel consists, on average, of 60% recycled steel (Bureau of International Recycling, -). This means 40% is still from virgin feedstock, it'll at least stay like that for the upcoming years as demand for steel is only increasing. Materials which stay in the biological cycle have the potential to be circular right now, as it is not dependant on waste, it is dependant on well maintained renewable sources. For many building materials, there are currently no biological solutions. For many other materials, there is only one supplier for that type of building material. Derbipure for example is the only biological roofing membrane currently available. This makes the materials very expensive, this doesn't incentivise clients to apply these materials. This can also be seen within the green redesign. The materials used are often more expensive than their technical counter parts, causing the return on investment to occur after the third, instead of second cycle.

Misused definitions and transparency of supply chains

While a lot of knowledge required for the assessment methods is publicly available, you need to be very careful with the credibility of sources. Many building materials are described as being a 100% recyclable, but not all are. Plastics are a notorious example and a lesser known example in this area is concrete. PIR is often advertised as a 100% recyclable, which isn't currently true. There is no economically viable recycling

method for PIR, the foam ends up down-cycled into a different application instead or is incinerated. This makes it difficult to examine which products are indeed fully recyclable, as there is a lot of misinformation. The recycling market is also ever evolving, many materials can be fully recycled, but it's currently not an economically feasible method. PIR is again the example here. Central knowledge on all materials would be needed, if we want to be able to make an substantiated decision. This data would be ever evolving, as more efficient and economical processes are introduced.

Long term commitment

A fully circular building stock would be the cheapest to maintain, but as this paper shows, getting there is difficult. While reuse of current materials is important, the Lidl design shows that it would be immensely difficult to fully construct a new building out of old materials. Much of their current design can't be reused, as demolition is the only option during a renovation. It requires a laid out design for the upcoming years. While certain construction principles and functions can change, completely generic dimensions and connections would be needed for an optimized reuse. The change to a fully circular building stock would take at least 50 years, if the Lidl would continue its current building development strategy. It requires a long term vision and a lot of patience. The initial investment will be higher compared to other design options, but after the product is reused the second or third time the investment will return.

Transferability

The research focussed on the Specification on one specific supermarket design, the freestanding supermarket. This is just one of the five types of supermarkets employed by the Lidl, these free standing supermarkets aren't numerous in the Netherlands. Many supermarkets are part of large scale housing projects and not an individual instance. This makes it difficult to determine which parts would be transferable to other supermarkets, many weren't even built by the Lidl. This is why the circularity on the indoor system is most important as a first step, the rest of the choices depend on a generic structure.

8.3. Recommendations for further research

The introduction of circularity shows many interesting opportunities in the built environment. Slowly, circularity is gaining traction in the building industry. This can be seen as more and more projects are starting to implement circularity, The Circular Building, the cityhall of Venlo and Brummen are just a few examples. The implementation for the Lidl would be interesting as well, as they have a large building stock. While this research gives a first step there is enough room for additional research left in this area.

A full circular assessment method

Introduce emissions and the biological cycle in the assessment methods. As shown in the discussion, the assessment methods are currently not complete. The methods only apply to a part of the principles at the foundation of the Circular Economy. Currently they don't include emissions or the biological cycle, making it impossible to say to compare two materials fully on their circularity. This also makes comparing biological to technological materials impossible. More research can be done on the inclusion of these two methods.

Recycling efficiency

The specific flows of materials aren't fully known in the Dutch waste industry. NIBE provides different results for the end-of-life scenarios of multiple products than suppliers in the specific branch do. How much of a building does actually get recycled, how efficient are these processes currently?

Economic viability

It is difficult to determine how much value would be saved by using a circular design. Within this research only the overall value was examined, the specific costs of the parts was left aside. Through literature and by examining the current price of building materials, an expectation was formed. The research didn't examine how, and if labour costs would be reduced for construction, or how expensive the deconstruction would be. How long will it take till the actual investment is returned if we also take maintenance into consideration? This would all play a part into the actual realization of a fully circular design.

Building a Lidl from construction waste

With an examination of the current building stock of the Lidl, which almost reaches 420 stores, an estimate can be made that around 20 supermarkets a year are renovated. During meetings with Arnold he said around four supermarkets a year are completely demolished and rebuild. It would be interesting to see if out of all the waste of these supermarkets, an actual supermarket could be constructed and how that would translate to the costs for building that new supermarket. It would be a good start to determine what would actually be necessary for storage for reusable parts, and further implementation of reuse within the Lidl's building strategy.

Supermarket in the biological cycle

The Lidl's current design is based fully within the Technological cycle of the Circular Economy. This research already shows for many major building functions a biological solution can be found, as structure, sandwich panels and cladding can all be taken from the Biological cycle. How much more of the construction can be taken from the biological cycle? How would these materials cascade when their technical life ends and how many cascaded cycles could fit within a single Lidl design?

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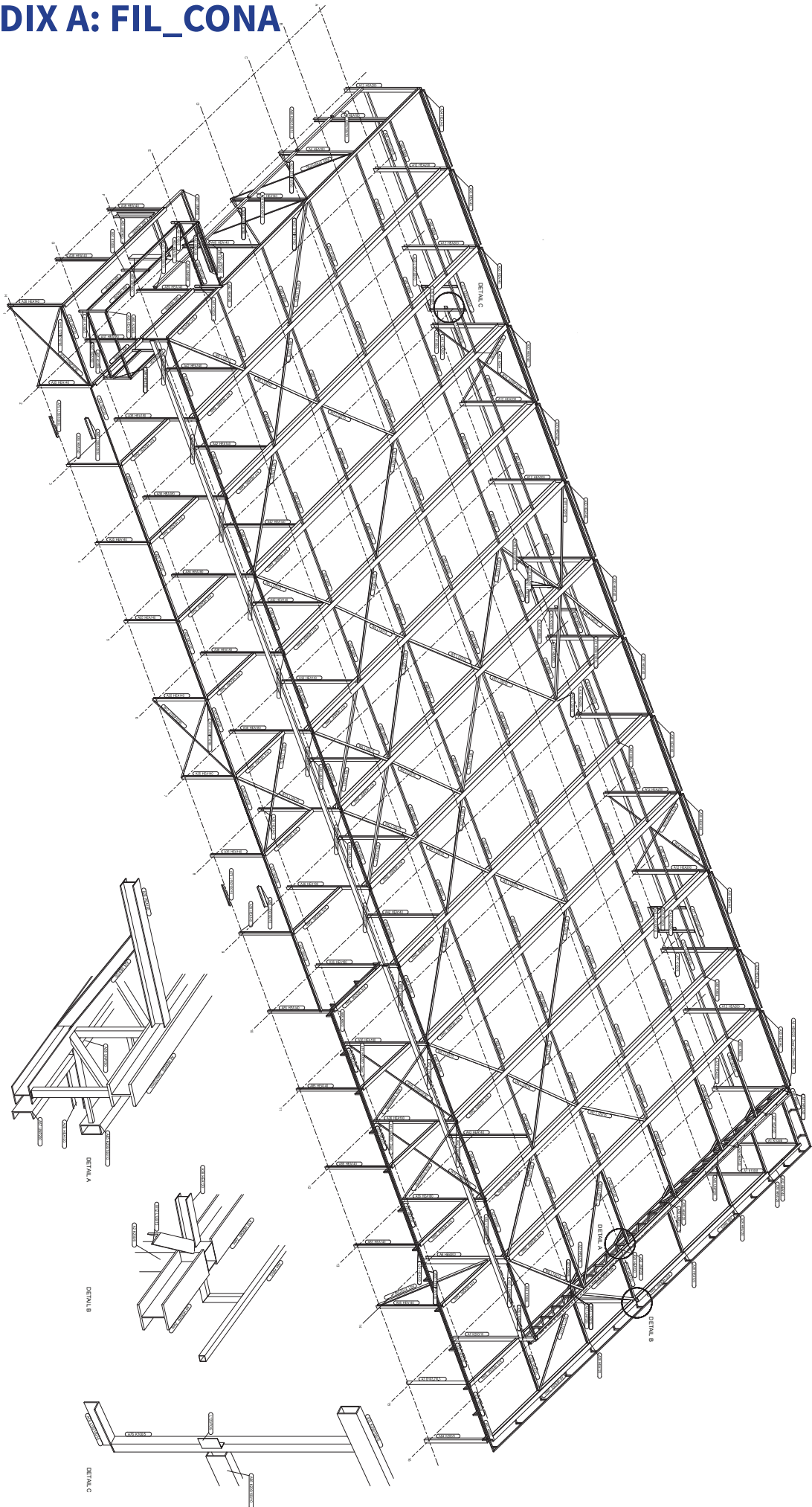
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APPENDIX A: FIL_CONA



APPENDIX B: DISASSEMBLY POTENTIAL GRADING FORM

FD FUNCTIONAL DECOMPOSITION	Functional separation (fs)	Separation of functions	1
		Integration of functions with same L.C. into one element	0.6
		Integration of functions with different L.C. into one element	0.1
	Functional dependence (fdp)	Modular zoning	1
		Planned interpenetrating for different solutions	0.8
		Planned interpenetrating for one solution	0.4
		Unplanned interpenetrating	0.2
		Total dependence	0.1

SY SYSTEMATISATION	Structure and material levels (st)	Components	1
		Element/components	0.8
		Elements	0.6
		Material/element/component	0.4
		Material/element	0.2
		Material	0.1
	Clustering (c)	Clustering according to the functionality	1
		Clustering according to material life cycle	0.6
		Clustering for fast assembly	0.3
		No clustering	0.1

BE BASE ELEMENT	Base element specification (b)	Base element- intermediary between systems/component	1
		Base element- on two levels	0.6
		Element with two functions (b.e. and building function)	0.4
		No base element	0.1

LCC LIFE-CYCLE COORDINATION	Use life-cycle/ coordination (ulc)	Long(1)/long(2) or short(1)/short(2)	1
		Long(1)/short(2)	0.8
		Medium(1)/long(2)	0.5
		Short(1)/medium(2)	0.3
		Short(1)/long(2)	0.1
	Technical life-cycle/ coordination (tlc)	Long(a)/long(b) or short(a)/short(b)	1
		Long(a)/short(b)	0.8
		Medium(a)/long(b)	0.5
		Short(a)/medium(b)	0.3
		Short(a)/long(b)	0.1
	Use life-cycle/ size(s)	Big (small) element / long L.C. or Big component / long L.C.	1
		Small element / short L.C. or medium component/ short L.C.	1
		Big component/ short L.C.	0.4
		Material/ long L.C.	0.2
		Big element / short L.C.	0.1

RP RELATIONAL PATTERN	Position and type of relations (r)	Vertical	1
		Horizontal	0.6
		Horizontal between upper and lower zone	0.4
		Horizontal in upper zone	0.1

A ASSEMBLY	Assembly direction (ad)	Parallel	1
		Stuck assembly	0.6
		B.e. in stuck assembly	0.4
		Sequential	0.1

G GEOMETRY	Geometry of product edge (ge)	Open linear	1
		Symmetrical overlapping	0.8
		Overlapping on one side	0.7
		Unsymmetrical overlapping	0.4
		Insert on one side	0.2
		Insert on two sides	0.1
	Standardisation of product edge (se)	Pre-made geometry	1
		Half standardised geometry	0.5
		Geometry made on site	0.1

C CONNECTIONS	Type of connection (gc)	Accessory external connection or connection system	1
		Direct connection with additional fixing devices	0.8
		Direct integral connection with inserts	0.6
		Direct integral connection	0.5
		Accessory internal connection	0.4
		Filled soft chemical connection	0.2
		Filled hard chemical connection	0.1
		Direct chemical connection	0.1
		Accessibility to fixings and intermediary (af)	Accessible
	Accessible with additional oper. which causes no damage		0.8
	Accessible with additional oper. with repairable damage		0.6
	Accessible with additional operation which causes damage		0.4
	Not accessible - total damage to elements		0.1
	Tolerance (t)	High tolerance	1
		Minimum tolerance	0.5
		No tolerance	0.1

APPENDIX C: PRELIMINARY STUDY

Preliminary Study

Circular supermarket design in the LIDL

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Where is the highest necessity for the circular approach within the supermarket chain?

Before we are able to assess the part where a building engineer can have the largest impact in a supermarket design, we need to look at the carbon and resource footprint of the supermarket chain as a whole. The supermarket chain consists out of many different faces, each with its own complications and influence of the carbon footprint as a whole. The LIDL doesn't have a elaborate study on this unfortunately. Trough research into a different supermarket, Booths, we are able to roughly determine what the impact of the LIDL would be.

Booths compared to LIDL

While searching for data about the impact of a supermarket chain, a consultation paper of "The greenhouse gas footprint of Booths" came up, done in association with the Lancaster University. This paper was released in 2015 and covers the years 2013-14 in detail. Though the LIDL has multiple papers on their carbon footprint, those papers are about individual products. The report about Booths contains information about the supermarket chain as a whole.

On first glance these two chains don't have much in common, first they are vastly different in size. While Booths has 28 stores all around UK(Booths, 2017b), and LIDL over 650(LIDL, 2017(1)) they seem incomparable. The same goes for the annual turnover, while booths had a turnover of 280 million in 2015, LIDL made over 4 billion. Though, when examining the smaller details, they have a more in common than you would suspect. They have around the same in size stores on average. Booths supermarkets range between the 18.000 and 25.000 square feet in size (around 1650 m² and 2300 m²)(Booths, 2017a). LIDL on the other hand has stores that range from 14.000 to 26.500 square feet(around 1300 m² and 2450 m²)(LIDL, 2017(2)).

While looking at the products both supermarkets sell, there seems to be a lot of similarity as well.

Even though they differ in size, there are parts of the Booths report that can be applied to the LIDL as well. Especially the percentage a certain source for the greenhouse gas has in the supermarket chain can give a general view on the impact of that source.

Booths carbon footprint results

The Booths report is divided into multiple sections and scales. The first scale is on the greenhouse gas emission of the complete supermarket chain, from farm to consumer.

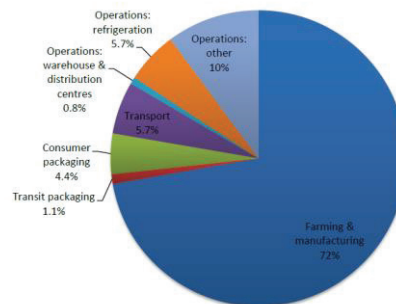


Figure 1: Total carbon footprint of Booths 279,048 tonnes CO₂ - (Berners-Lee, Moss, & Hoolohan, 2015)

The first thing to note is the amount of CO₂ used in "Farming & manufacturing", this amounts to over 2/3 of the footprint of the chain as a whole. "Transport" and "Cooling" share a space as second and third largest contributors to the Carbon footprint. Followed closely by "Consumer packaging" at a fourth place. "Operations: Other" is a combination of multiple carbon gas sources that will be discussed further after figure 5. In figure 5 all the parts with Operations are looked at again in further detail. The next topic of discussion is transportation, with the second largest impact.

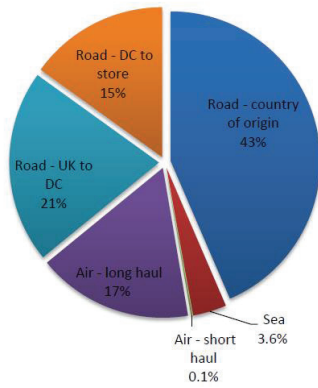


Figure 2: Transport 15.862 tonnes CO2 (Berners-Lee et al., 2015)

As figure 4 from the report shows, its largest contribution to transport is the transport by road, most of it is caused by the transportation of goods on their native location towards the sea freighters. The emissions from road transport in the UK itself is a lot lower due to the close proximity of the distribution centre to the stores. One of the most notable parts in this graph are the relation of sea to air and road. While sea is responsible for the most food miles out of all the modes of transport, it has by far the lowest impact. Air transport has the highest footprint per food mile. The most important thing to take away from this is that it is more important that a product is grown in its native habitat and moved by sea than that it is grown in close proximity to the store.

This leads to the operations of the supermarket itself. Described in figure 5 is the carbon footprint of the supermarket operations itself. The first thing to note is the amount of the footprint taken up by Cooling and the refrigerators loss of coolant gasses. Together they end up causing 36% of the carbon footprint of the supermarket. Electricity ends up being just 17% of the total. Waste has become low for stores due to the high rate of recycling over the past few years and the returning of packaging materials used during transport to the manufacturer of the products.

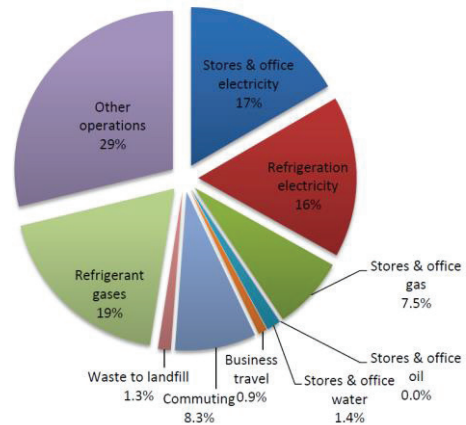


Figure 3: Operations 44,978 tonnes CO2 (Berners-Lee et al., 2015)

Heating of the stores during winter can be attributed to both gas and electricity. Over the years the oil based heating systems have been changed to gas and they are slowly being changed towards electricity to try to reduce the need for fossil fuels in stores even further (Berners-Lee et al., 2015).

Material footprint of a supermarket building.

This gives an overview of the parts of the supermarket chain which contribute most to the carbon footprint of the supermarket. But as noted they all fall outside of the building envelope, and one thing missing from the equation seems to be the carbon footprint of the supermarket buildings themselves. How much does a supermarket cost to build. Instead of money we examine the embodied energy and carbon footprint of the materials needed in the building. Because of the average size of the supermarket chain being known, we can use a study into the life cycle assessment of building materials to determine how much carbon the building would have cost to build. The study, performed by the University of Zaragoza, examined 60 studies into the material costs of different buildings all around the world. Through this they were able to distil how much an building would cost on average per square meter (Zabalza Bribian, Valerio capilla, & Aranda Usón, 2010). This resulted in an estimate of 0.5 tonnes of CO2 per square meter. We know that the average size of the

supermarket structures build by Booths is, as determined in the previous chapter, between the 1650 m² and 2300 m². A rough estimate means that it is 2000 m² per supermarket.

This would lead to an estimate carbon footprint of 1000 tonnes of CO₂ per supermarket. Extrapolated over all 28 supermarkets this means a footprint of 28.000 tonnes of CO₂ in total. Compared to the yearly footprint of the whole branch this would be 10%, if every year they would completely rebuild all their supermarkets. In England they use an average building life of 60 years(Zabalza Bribian et al., 2010), this would mean the footprint would be 0.17% of the yearly carbon footprint. Of course distribution centres and offices are still missing from the equation, but even if it would double the used building materials it would only be 0.34% of the yearly carbon footprint.

Priorities

As determined in the last chapters, the priorities of the supermarket can be concluded to be in the order of impact and percentage of the carbon footprint:

- Farming and manufacturing 72%
- Cooling 5.7%
- Transport 5.7%
- Packaging 4.4%

The buildings themselves are very low on the list with only a yearly impact of a maximum of 0.34%. While other changes have a bigger impact on the carbon footprint within Booths, for the LIDL the priorities change. Due to the difference in size and ambition the impact of the LIDL on a building level becomes quite significant. Where Booths only has 28 stores around the UK, the LIDL already has a large building portfolio, with over 10.000 shops around the globe, in 27 countries. The LIDL wants to expand a lot further than just these supermarkets, in the UK they want to double their current market share, from 650 shops to over 1200 in the upcoming years(LIDL, 2017(2)). In June 2017 they opened their first

buildings in America. At the end of 2017 they aim to have opened over 60 and in the upcoming years they want to open 600 more according to the business insider(Peterson, 2017). These staggering numbers suddenly show a far larger share in the embodied energy of their buildings than the booths chain. In the Netherlands they are currently responsible for 415 shops according to the LIDL's website and planning to open at least 100 more. Besides that, there is a constant demand for new buildings. According to the Dutch government, Office and utility buildings in the Netherlands have a general life time of 20 years before they are renovated or rebuild(Zabalza Bribian et al., 2010). The Lidl supermarkets overhaul their interior every eight years, due to the rapid changes in demand from shoppers. This would seem to request for flexibility to address this every changing functionality(LIDL, personal communication 20-3-2018).

Even if it has a low share within the yearly carbon footprint of the LIDL as a chain, the material footprint is staggering and needs to be tackled, in the building industry as a whole and especially in a fast changing industry where you want to be able to update and upgrade your buildings every 20 years. If you're able to change your portfolio without requiring new, expensive materials you'll be able to upgrade and refresh faster with a lower environmental and economic impact. The CO₂ required to manufacture those materials once isn't required again if the materials can be reused in their highest quality without requiring a new energy investment.

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APPENDIX D: MCI GRADES SPECIFICATION

Step1: Calculate Virgin Feedstock

Specification Code	Material	M(x) (kg)	F _R	F _U	V (kg)
14	02 Buitenriolering	10.8	0%	0	10.8
	04 Hemelwaterafvoeren	3.5	60%	0	1.4
20	02 Geprefabriceerd beton	17.246	20%	0	13.7968
	03 Betonschroef boorpaal	22.834	20%	0	18.2672
21	04 Beton	425.9	20%	0	340.72
22	02 Kalkzandsteen	180	20%	0	144
	02 Baksteen	180	0%	0	180
	03 Spouwmuur isolatie	3.3	0%	0	3.3
24	01.04. Plywood	31.5	0%	0	31.5
	04 HSB elementen	31.5	0%	0	31.5
25	02 Staalconstructiewerk	60	60%	0	24
	04 Staaldak	6.9	60%	0	2.76
30	04 Houten Kozijn	2.8	0%	0	2.8
	05 Stalen Kozijn	3.1	37%	0	1.953
	05 Aluminium Kozijn	3.8	30%	0	2.66
	06 Houten Deur Paneelspaan	21.3	0%	0	21.3
	06 Houten Deur Volspaan	21.3	0%	0	21.3
	07 Panelen Sandwich	15.75	0%	0	15.75
	10 Vliesgevelsysteem	13.63	30%	0	9.541
31	03 Alucobond	6.3	47%	0	3.339
	04 Lamellen bekleding	22.6	49%	0	11.526
	05 Sandwich paneel	12.7	15%	0	10.795
33	33.03 Sarnavap 1000 PE-LD	0.2	0%	0	0.2
	04 Dak isolatie	4.8	0%	0	4.8
	05 FPO Dakbedekking NIBE	3.2	0%	0	3.2
	05 FPO Dakbedekking 85%	3.2	0%	0	3.2
34	03 Gelaagd glas	15	63%	0	5.55
	04 Meerbladig isolatieglas	15	63%	0	5.55
	05 Glaspaneel	28.8	63%	0	10.656
35	02 Hardsteen	8.1	0%	0	8.1
	03 Composietsteen	10.9	0%	0	10.9
37	02 Glaswol	12	70%	0	3.6
	03 Glaswol full recycling	12	70%	0	3.6
	03 Hardschuim	2.1	0%	0	2.1
	04 Steenwol	5.6	0%	0	5.6
	05 PIR	4.8	0%	0	4.8
38	02 Buitenjaloezieën				
	02 Rolscherm Binnen				
40	02 Pleisterwerk	16	0%	0	16
41	02 Wandtegels Keramisch	22.6	0%	0	22.6
	04 Vloertegels Keramisch	43.2	0%	0	43.2
42	02 Dekvloer Cement	97.5	0%	0	97.5
44	02 Rasterplafonds	3.2	0%	0	3.2
	03 Panelenplafonds	6	0%	0	6
	04 Gipsplaatplafond	10.6	0%	0	10.6

Step1: Calculate Virgin Feedst

Step2: Calculate Unrecoverable Waste

Specification Code	Material
14	02 Buitenriolering
	04 Hemelwaterafvoeren
20	02 Geprefabriceerd beton
	03 Betonschroef boorpaal
21	04 Beton
22	02 Kalkzandsteen
	02 Baksteen
	03 Spouwmuur isolatie
24	01.04. Plywood
	04 HSB elementen
25	02 Staalconstructiewerk
	04 Staaldak
30	04 Houten Kozijn
	05 Stalen Kozijn
	05 Aluminium Kozijn
	06 Houten Deur Paneelspaan
	06 Houten Deur Volspaan
	07 Panelen Sandwich
	10 Vliesgevelsysteem
31	03 Alucobond
	04 Lamellen bekleding
	05 Sandwich paneel
33	33.03 Sarnavap 1000 PE-LD
	04 Dak isolatie
	05 FPO Dakbedekking NIBE
	05 FPO Dakbedekking 85%
34	03 Gelaagd glas
	04 Meerbladig isolatieglas
	05 Glaspaneel
35	02 Hardsteen
	03 Composietsteen
37	02 Glaswol
	03 Glaswol full recycling
	03 Hardschuim
	04 Steenwol
	05 PIR
38	02 Buitenjaloezieën
	02 Rolscherp Binnen
40	02 Pleisterwerk
41	02 Wandtegels Keramisch
	04 Vloertegels Keramisch
42	02 Dekvloer Cement
44	02 Rasterplafonds
	03 Panelenplafonds
	04 Gipsplaatplafond

M(x) (kg)	C _R	C _U	W ₀ (kg)	E _R	W _C (kg)	E _F	F _R	W _F (kg)	W (kg)
10.8	70%	0%	3.1968	100%	0	20%	0%	0	3.1968
3.5	70%	29%	0.035	100%	0	100%	60%	0	0.035
17.246	99%	0%	0.103476	20%	13.65883	20%	0%	13.65883	13.76231
22.834	99%	0%	0.137004	20%	18.08453	20%	0%	18.08453	18.22153
425.9	98%	0%	5.9626	20%	334.587	20%	20%	340.72	343.6161
180	92%	0%	15.12	20%	131.904	20%	20%	144	153.072
180	68%	0%	57.24	0%	122.76	100%	0%	122.76	180
3.3	6%	0%	3.1053	0%	0.1947	100%	0%	0.1947	3.3
31.5	6%	0%	29.547	0%	1.953	100%	0%	1.953	31.5
31.5	6%	0%	29.547	0%	1.953	200%	0%	1.953	31.5
60	51%	49%	0	100%	0	100%	60%	0	0
6.9	70%	29%	0.069	100%	0	100%	60%	0	0.069
2.8	0%	0%	2.7944	0%	0.0056	100%	0%	0.0056	2.8
3.1	93%	0%	0.2139	100%	0	100%	37%	0	0.2139
3.8	63%	0%	1.406	100%	0	100%	30%	0	1.406
21.3	0%	0%	21.3	0%	0	100%	0%	0	21.3
21.3	4%	0%	20.4267	0%	0.8733	100%	0%	0.8733	21.3
15.75	47%	20%	5.229	100%	0	100%	0%	0	5.229
13.63	77%	10%	1.7719	100%	0	100%	30%	0	1.7719
6.3	80%	0%	1.26	100%	0	100%	47%	0	1.26
22.6	87%	6%	1.6272	100%	0	100%	49%	0	1.6272
12.7	47%	20%	4.2164	90%	0.59944	100%	15%	0.59944	4.81584
0.2	5%	0%	0.19	100%	0	100%	0%	0	0.19
4.8	4%	0%	4.6032	100%	0	100%	0%	0	4.6032
3.2	6%	0%	2.9888	100%	0	100%	0%	0	2.9888
3.2	85%	0%	0.4736	100%	0	100%	0%	0	0.4736
						100%	0%	0	0
15	70%	0%	4.5	100%	0	100%	63%	0	4.5
15	70%	0%	4.5	100%	0	100%	63%	0	4.5
28.8	0%	0%	28.8	100%	0	100%	63%	0	28.8
8.1	0%	0%	8.1	0%	0	100%	0%	0	8.1
10.9	10%	0%	9.81	20%	0.872	100%	0%	0.872	10.682
12	10%	0%	10.8	100%	0	100%	70%	0	10.8
12	100%	0%	0	100%	0	100%	70%	0	0
2.1	10%	0%	1.89	100%	0	100%	0%	0	1.89
5.6	100%	0%	0	100%	0	100%	0%	0	0
4.8	4%	0%	4.6032	0%	0.1968	100%	0%	0.1968	4.8
16	0%	0%	16	0%	0	100%	0%	0	16
22.6	86%	0%	3.1866	0%	19.4134	100%	0%	19.4134	22.6
43.2	54%	0%	19.6992	0%	23.5008	100%	0%	23.5008	43.2
97.5	0%	0%	97.5	0%	0	100%	0%	0	97.5
3.2	82%	0%	0.5824	100%	0	100%	0%	0	0.5824
6	10%	0%	5.4	0%	0.6	100%	0%	0.6	6
10.6	15%	0%	9.01	0%	1.59	100%	0%	1.59	10.6

