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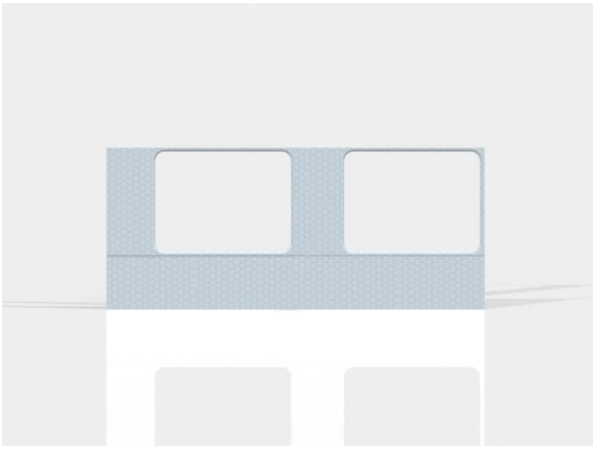
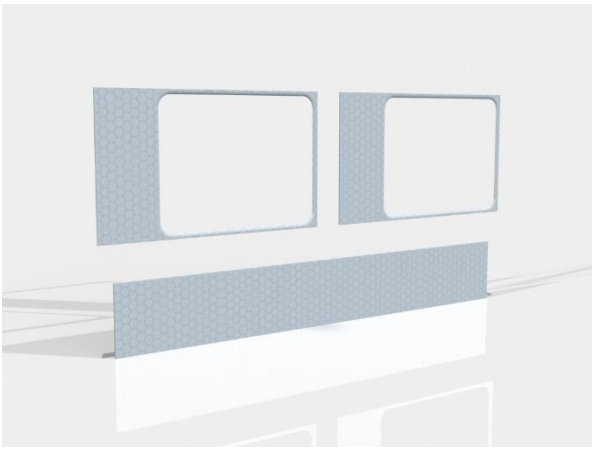

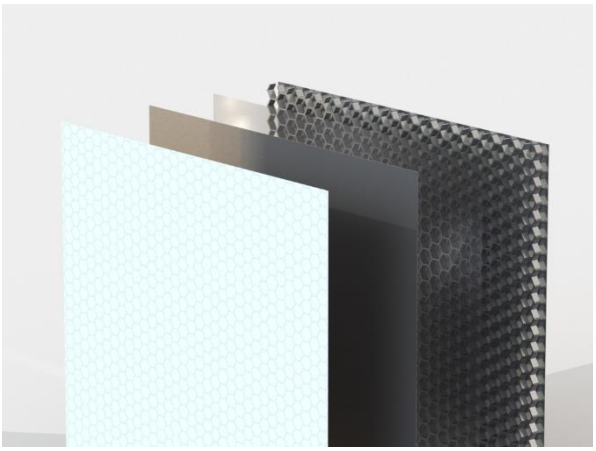

CIRCULARITY IN THE DUTCH TRAIN

MASTER GRADUATION THESIS INDUSTRIAL DESIGN ENGINEERING

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1 SUMMARY

The vision of NS is to provide 'Sustainable accessibility within the Netherlands. For everyone'. Part of this mission includes making the transition towards fully circular trains in 2030. This means a large share of the trains will have to be processed in a circular manner during the modernisation and dismantling, and that new trains will have to be designed in a circular manner. This is a big challenge, as a train is a very big and complex product, bound by a wide range of very strict operational and safety regulations.

This graduation project makes a contribution to this complex challenge by researching the question "How can NS achieve circular inflow and outflow during building, modernisation and end-of-life for the train interior, car body and bogies?". Through multiple analyses and explorative design visions, the train interior side wall panel was selected as design concept. The current side wall panel is made of glass fibre polyester composite, which is difficult to reuse or repurpose, and cannot be recycled. A sustainable alternative was developed which made use of recyclable aluminium honeycomb materials, and a dismountable structure due to the use of reversible Niaga adhesive. The flat shape of the panel combined with the optimized surface distribution increase the available panel size, which increases the potential for reuse or repurpose. Additionally, the wall panel is finished through the use of coloured foil instead of paint as this reduces toxic substances and improves cleanability, readjustability and recyclability. It also gives additional customization options to the panel, such as integrating a honeycomb pattern to illustrate the circular construction.

This report also reflects on the application of design methodology by researching the question "How can design methodology be used to structure a complex design project?". Two design methods were chosen for this: the 1:10:100 approach and the Design Roadmapping methodology.
The 1:10:100 approach was chosen as this is suitable for open-ended projects. I found that the 1:10:100 method was very useful to quickly determine a project scope but it lacked structure within the '100' cycle. I found the midterm and green light graduation deadlines to be useful additions to further structure the iterative process.
Design Roadmapping was chosen as it combines future roadmapping and design. NS was interested in creating a roadmap towards fully circular trains, whereas the Industrial Design Engineering department was interested in my skills as concept designer. The roadmap has not been finished within the timespan of this project, but this report makes good progress along the analyses steps of this method. Additionally, I felt this method helped me to keep focus on the future instead of focusing too much on current practice.

2 INTRODUCTION

This project is a master graduation project for the study Industrial Design Engineering (IDE) at Delft University of Technology (TU Delft). It is part of the Integrated Product Design (IPD) direction, but also includes Strategic Product Design (SPD) elements. The project client was the sustainability department of NS (Nederlandse Spoorwegen, the main Dutch railway company). This chapter will discuss the challenge set by NS, as well as my research questions and project approach. In the next three chapters, the three iteration cycles within the project will be discussed. The results and insights from these iterations led to a future roadmap, and a concept design to give a concrete example of how to work towards the future vision in the roadmap.

2.1 PROJECT CONTEXT

This paragraph will describe the problem provided by the project client. Firstly, the general challenge for NS will be discussed, followed by the specific scope for this project. The second section will give more background on NS as a company by outlining the company mission and vision, and explaining how sustainability is secured within the company.

| 2.1.1 Transition towards fully circular trains

The mission of NS is to provide sustainable travel within the Netherlands, for everyone. Part of this mission is to become fully circular in 2030, which includes the shift towards circular trains. This is a big challenge. A train is a very complex product, bound by a wide range of very strict operational and safety regulations. Trains also have a long product lifetime, which means that it takes long before decisions take effect: the trains that we have today were never designed with circularity in mind. This makes that even though maintenance, repair and remanufacturing are quite common, it is difficult to process the train in a fully circular manner at the end of life. Additionally, the train market is very conservative owing to the strict safety regulations, which makes it difficult to realize change. On the other hand, train materials still hold a large amount of residual value. Train parts are designed to be 'hufterproof', adhere to strict regulations and are made to last a long time. Besides, the materials are available in large volumes, which can make it easier to realize a structural solution.

Figure 1 shows the current train lifecycle. In this lifecycle, there are three phases in which material flows are created: building, modernisation and end-of-life.

| 1. Building
NS doesn't build their own trains, but instead runs tenders to find the right train builder. For this, a long list of requirements is composed with the help of all relevant NS departments.

| 2. Modernisation
After a train has been built, it runs for about 15 to 20 years. Then, most trains are modernised: they are stripped completely, all technical parts are serviced and/or replaced, and the interior is updated. The modernisation is done internally at NS.

| 3. End-of-life
After modernisation the train can run for another 15-20 years, but eventually it reaches end-of-life. If a train cannot be sold, it is selected for dismantling, again via tender contracting. The train is sent as a whole to a dismantling plant, where a big grappler pulls the train apart. Most of the train body can be recycled, but the interior holds a lot of mixed materials which are difficult to separate for recycling.

Between these phases, there are also material flows in and out of the train, for example during maintenance, repair and design reconfigurations. However, as these flows are less significant they will not be considered in the current scope.

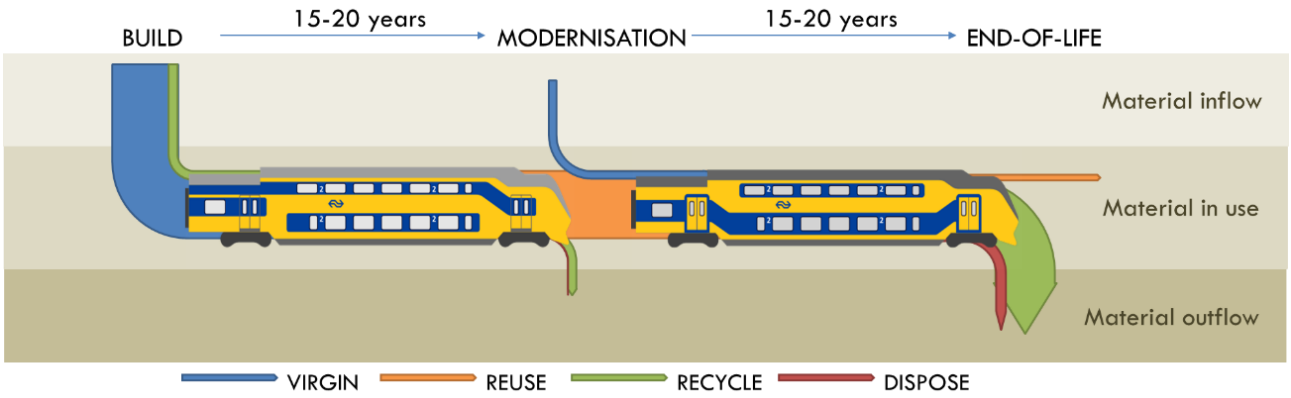


Figure 1: Own visualization of current train lifecycle

Figure 1 shows that the main material inflow consists of virgin material. There is a small percentage of recycled material, for example in the steel bogies and likely also in the general market mix of some materials, but the conscious use of recyclates in the train is still very limited. Additionally, not all materials can be reused or recycled during the modernisation or at the end-of-life. To make the transition towards circular trains, NS needs to minimize both the inflow of virgin materials and the disposal of used materials within each phase, such as visualized in Figure 2. This raises the question which changes are needed to transit from the current lifecycle towards the circular lifecycle, and what the best focus is within this project.

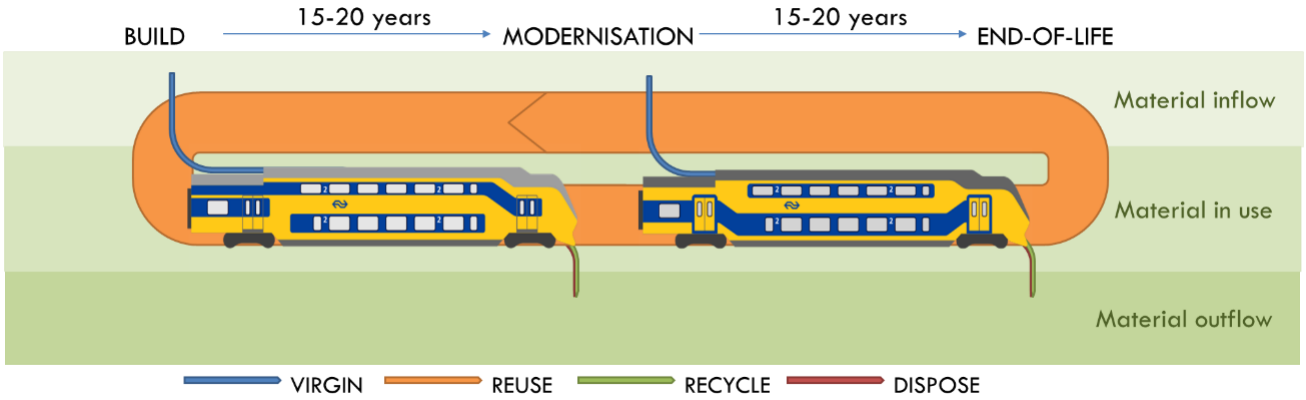


Figure 2: Own visual of circular train lifecycle

This project initially considered all three material flow phases to see which phase would be most interesting. For the outflow, NS is currently setting up a circularity baseline measurement. For this, they want to map what materials are currently used in trains, which percentages are not recyclable, and how to take care that these materials are processed in a circular manner from 2030 on. For the inflow of new materials, NS envisions is constructing a material handbook to present guidelines and inspiration on sustainable change.

After the first iteration, it was decided to focus mainly on the inflow of materials in the building/modernisation phase as this makes it possible to create a structural future impact. As discussed in the previous paragraph, NS has in the past mainly applied the Ladder van Lansink to find the most suitable end-of-life solution. With their new vision however, the Trias Circular NS, focus is placed more structurally on the front-end. By taking the next lifecycles into account during the design, circularity will be much easier to realize during the modernisation and end-of-life phases in the future. To keep the project manageable, only the train interior, car body and bogies were considered for the material flow. The car body and bogies were selected as these hold the largest weight percentage in the train, and interesting when looking to apply recycled materials. The interior was chosen as this flow has the largest percentage of materials that are not recyclable. The interior is also more interesting from a design perspective compared to the car body and bogies.

| 2.1.2 Sustainable entrepreneurship at NS

In order to realize a circular transition at NS, it is important to know how the company is structured, and how sustainability is secured within the company. The main business focus of NS is the travellers' journeys from A to B. People want to be able to move around without having to worry. Fast, safe, simple and at any time. To enable safe and accessible travel, NS provides an extensive network of railway travel. However, NS does not limit itself to just trains: a wide range of additional services is offered to facilitate a comfortable and seamless door-to-door journey (NS, n.d.).

Figure 3 shows the company structure of NS. NS is a large company with a wide range of departments and partners. In 2019, NS held 20.074 employees in the Netherlands alone, which makes them one of the largest employers in the Netherlands (11th place). In addition, about 1 in every 300 jobs in the Netherlands is directly or indirectly linked to NS activities. The company also holds 5th place in the ranking of favourite employers in the Netherlands (NS, 2020-b). Being a large company means that there is a lot of in-house capacity and knowledge, and ample opportunities for partnerships. However, it can also make things very complex.

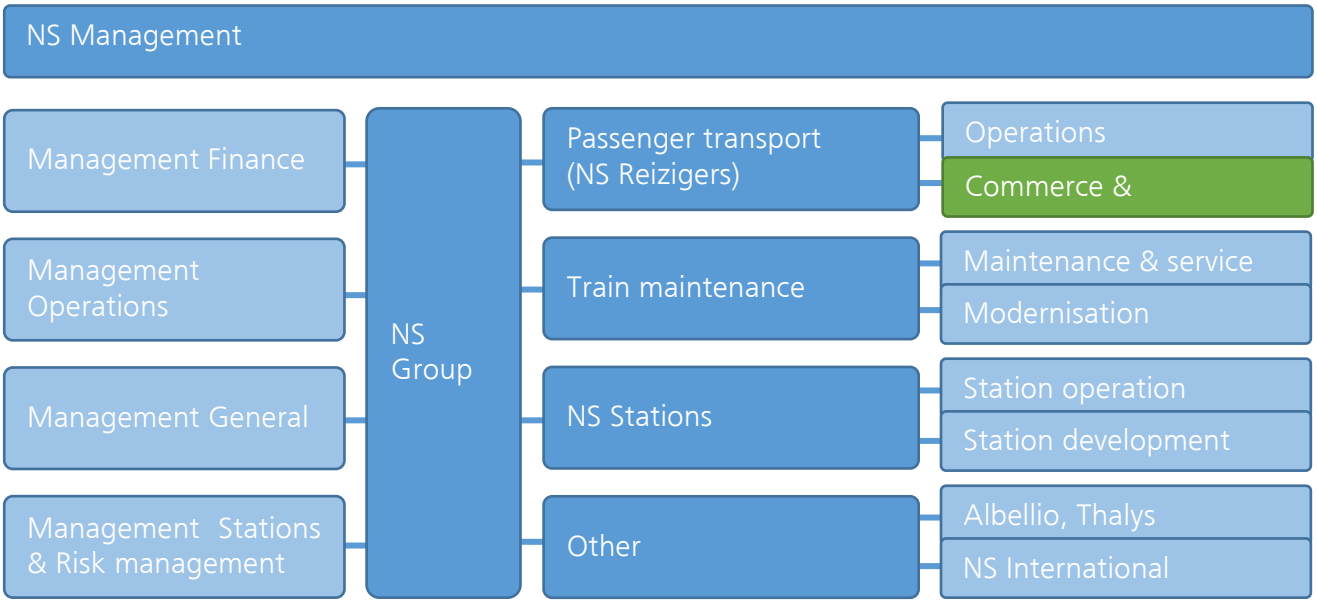


Figure 3: NS corporate structure

The mission of NS is 'Sustainable accessibility within the Netherlands. For everyone' ('Nederland duurzaam bereikbaar. Voor iedereen'). NS sees that travellers and their desires are changing, and that the accessibility of the Netherlands is under pressure. Other things to consider are climate goals, energy transition, shortage of living space, new providers and types of mobility, and fast changes in technological growth. This means that NS has to keep up, but also that there are a lot of opportunities (NS, 2020-a). NS sees that different mobility types will start to merge, and availability of both mobility and service will become more important. Flexibility, ease and comfort are key in this (NS, 2020). NS wants to meet the demand of future travellers on three themes (NS, 2020-a):

The train and network of the future
"Deliver a powerful and vital network in the Netherlands where the stations and main railway network are an integrated whole. We ride modern trains with a high level of comfort."

Stations as a hub for mobility and liveability
"Create hotspots where all sorts of transport seamlessly join together. A place where you want to work, live near to, or to shop or get something to eat."

Flexible and versatile travelling with the NS app
"Provide travel times as well as an overview of the whole door-to-door journey. NS works with colleagues and partners to offer travellers all suitable options on their journey."

By operating along these themes, NS ensures that they contribute to a mobile and accessible society and that they will be able to compete with other means of transport in the future mobility context. But besides customer satisfaction, NS also sees sustainable entrepreneurship as a precondition for successful future operation. Traveling by train is more sustainable than most means of transport, and a way for people to connect and socialize. Also, with over 1.3 billion train and bus journeys and about equally as many visits to train stations, NS has a large impact on the society and stands in the public eye. NS has become a frontrunner in sustainable mobility, and wants to hold this position (NS, n.d.). NS does this through the use of sustainable entrepreneurship, with a specific department set up to manage and facilitate sustainable change. The sustainable entrepreneurship department is housed at NS Reizigers under the Commerce and development department, as indicated in green in Figure 3.

Sustainable entrepreneurship at NS is divided into three pillars, which are Fossil-free, Circular and the newly added Green entrepreneurship, as shown in Figure 4. Fossil-free entrepreneurship focuses on energy-efficient operation and renewable energy, for example through hourly matching and acquisition of solar and wind energy. Circular entrepreneurship focuses on reducing waste streams, increasing the use of recycled and recyclable materials, and finding new applications for non-recyclable materials. Green entrepreneurship is focused on biodiversity and health, by realizing green spaces at stations, workplaces and vacant lots and offering healthy alternatives at station restaurants. Through these pillars, NS wants to provide sustainable travel and contribute to the Paris Agreement and the Sustainable Development Goals. This report will focus on circular entrepreneurship.

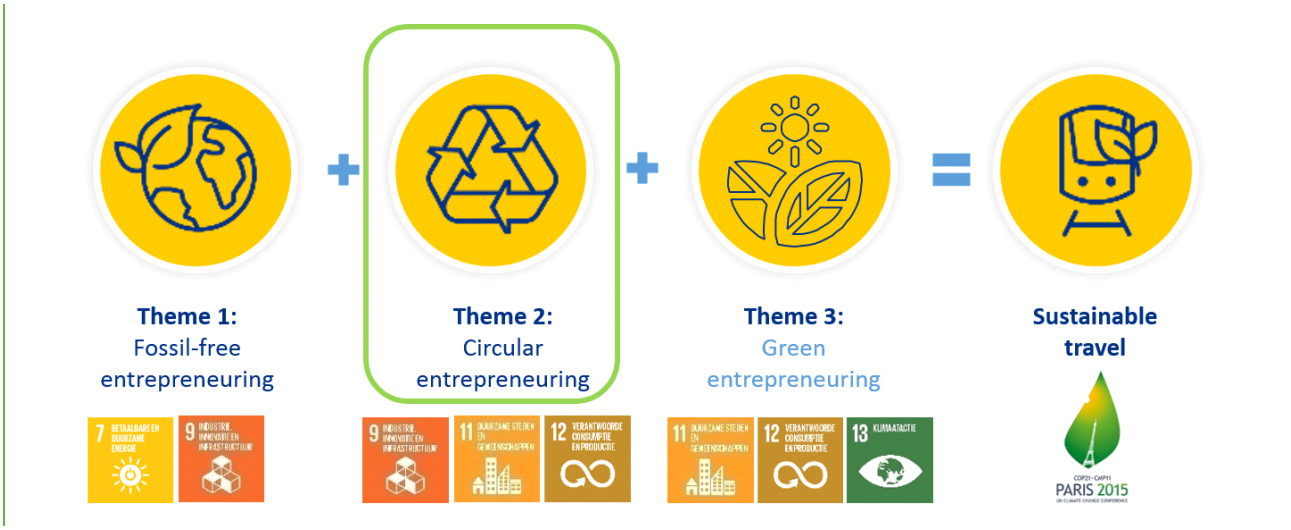


Figure 4: The themes within sustainable entrepreneuring at NS.

Circularity at NS uses two frameworks to shape its activities: the well-established Ladder van Lansink and the new Trias Circular NS, as explained on the next page. The frameworks are used to inspire, prioritize and focus circular activities. Through this process, circular milestones towards circular inflow and circular outflow can be formulated. Also, the frameworks can be used to communicate these priorities among different NS departments, and to external partners and stakeholders. For example, the Ladder van Lansink is used to communicate how desirable certain waste processing methods are.

The Ladder van Lansink (Figure 5), or Waste Hierarchy, is a standard in the waste industry that describes the desired level of waste processing. Each step higher on the ladder is a more desirable way to process waste. Below, the steps of the ladder are listed together with the corresponding governmental waste directive definitions (Lansink, 1979; Ministerie van IenW, 2019). The Trias Circular NS (Figure 6) is constructed by NS as part of the refined sustainable corporate strategy. It describes three main principles that NS will adhere to in order to become fully circular in 2030. Each principle also corresponds with a number of the ten R's of sustainability, as indicated in Figure 6.

LANSINK'S LADDER – THE WASTE HIERARCHY

Figure 5: The Ladder van Lansink (Waste Hierarchy)

| 1. Reduce/Prevent Measures that are taken before a substance, material or product becomes waste in order to reduce the amount of waste, harmful substances or negative environmental impact.

| 2. Reuse Activities where products or components that are not waste materials are reused for the same purpose as they were intended for.

| 3. Recycling Useful applications where waste materials are reprocessed into products or materials for the same or for a new application. This excludes energy recovery or use as fuel or filler.

| 4. Incineration for energy recovery The incineration of waste materials with as main purpose to use the waste materials as fuel. This way, the waste replaces a primary (virgin) energy source.

| 5. Incineration The incineration of waste materials in facilities built specifically for the incineration of waste, even when energy or heat is (partially) recovered.

| 6. Landfill Placing waste materials on/inside the ground with the intention of leaving them there.

TRIAS CIRCULAR NS

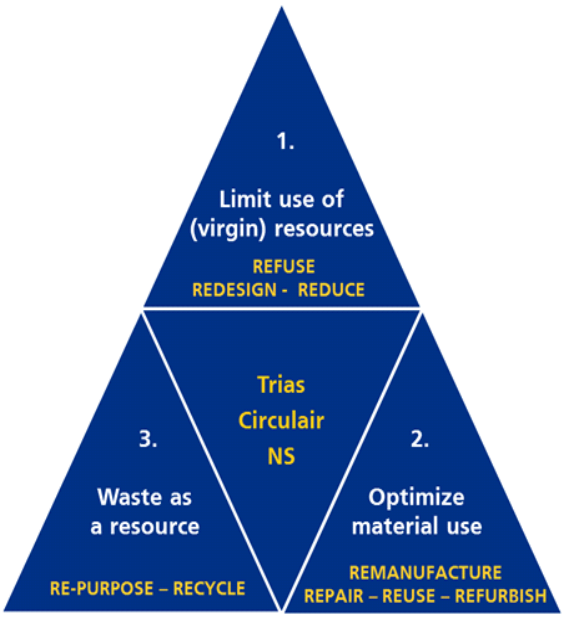


Figure 6:: Trias Circular NS framework

| 1. Limit use of (virgin) resources
Refuse – Redesign – Reduce
This accounts for both standard and specifically designed parts. The main key points in limiting use of resources are smart purchasing, circular design and low material use, use of mono-materials, and choosing renewable and recycled resources

| 2. Optimize material use
Reuse – Repair – Refurbish – Remanufacture
NS is efficient with their materials and products. NS strives for longer and optimal use of products and parts, and focuses on good maintenance, repair and lifetime extension.

| 3. Waste as a resource
Repurpose – Recycle
Everything that leaves the company, gets a new purpose (upcycling, reuse or recycling), through which NS closes the loop (within the company). NS acts as an inspiring example, collaborates, and drives innovation.

2.2 RESEARCH QUESTIONS

From the previous paragraph, the question was raised how NS can transition towards fully circular trains, and additionally how this project can best contribute to this widely scoped and complex issue. This creates a two-fold research question, with one aimed at the project contents, and one aimed at project process. The former will be more of interest for NS as it provides concrete results and recommendations, and makes a contribution towards the roadmap towards circular trains that NS wants to establish. The latter will be more of interest to make a contribution towards scientific design research and the application of design methodology and concept design in a sustainability context. The design methods that were chosen for this project are the 1:10:100 approach and Design Roadmapping, as explained in the next paragraph.

	RESEARCH	**DESIGN**	**METHODOLOGY**
Main question	"How can NS achieve circular inflow and outflow during building, modernisation and end-of-life for the train interior, car body and bogies?"		"How can design methodology be used to structure a complex design project?"
Sub-questions	1. How is circularity employed at NS? 2. What are the material inflows and outflows of a train? 3. What are roadblocks towards circular inflow and outflow? 4. What can NS do to overcome these circular roadblocks?	1. What is the future design vision for circular trains? 2. What does the roadmap towards circular trains look like? 3. How can concept design contribute to achieving circular trains?	1. How can '1:10:100' help to structure complex design projects? 2. How can design roadmapping be used in a circularity context?
Results	❖ Overview of train and material flows ❖ List of circular roadblocks	❖ Design vision ❖ Roadmap towards circular trains ❖ Concept design	❖ Insights into the application of design methodology

2.3 PROJECT METHODOLOGY

The project has a very wide scope, and the research questions outline a lot of questions, sub-questions and envisioned activities. This means that it is important to structure the project, to prioritise activities, and to gain a good project focus very quickly. Also, there were various interests from both parties involved: NS is looking for a roadmap to make the transition to fully circular trains, whereas the IDE faculty is more interested in my skills as a concept designer. To balance the project and expectations, two main project methods were chosen: 1:10:100 approach and Design Roadmapping. Additionally, co-reflective practice was used. All used methods are explained in more detail below.

A good design project moves through multiple iterations and reflections. Figure 7 shows a general overview of the content of the iteration cycles within the project. All iterations of my project consisted out of four main phases: question, research, design and conclusion, followed by co-reflection. The iteration moved back and forth between these phases, adjusting activities along to gained insights.

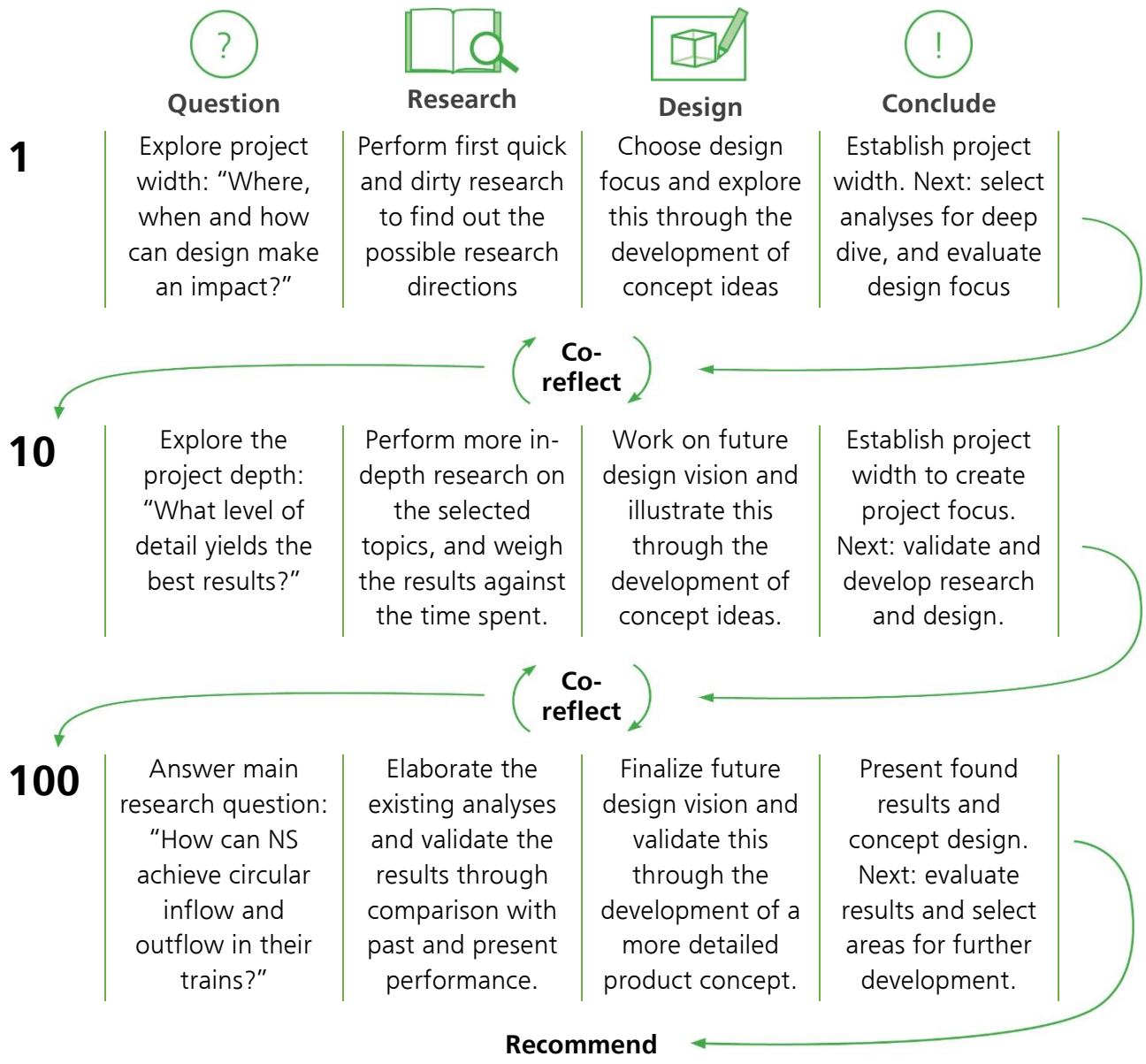


Figure 7: Project approach

| 2.3.1 1:10:100

The assignment for this project had a very wide scope. In order to work on it efficiently, it needed to be focused further. To shape the process and create focus, the 1:10:10 approach was chosen. This approach is suitable for open ended design projects where there is no clear idea of the preferable solution upfront (Van Turnhout, Leer, Ruis, Zaad, & Bakker, 2012). It was conceived to bring 'hindsight' into design projects and to align 'research' activities with 'design' activities (Dorst, 2006). It actively encourages discovery in a design project, and it is very flexible and open to growing insight (Van Turnhout, et al., 2013). The idea of the 1:10:100 method is to go through three complete design cycles with a length of respectively 1, 10 and 100 days (Dorst, 2006). Each cycle holds all traditional design phases. At the end of each cycle there is an evaluation session with all the stakeholders. Within the design cycles, various other design methods

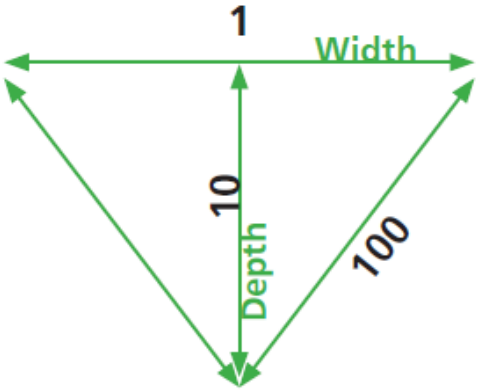


Figure 8: T-model for establishing project focus with the use of 1:10:100

can be used (Van Turnhout, et al., 2013). In this project, the 1:10:100 method was combined with Design Roadmapping, as explained in the next paragraph.

The focus of the project was established by determining the project width and depth, as shown in the T-model in Figure 8. This figure also shows how the iterations of the 1:10:100 method were used: the width was first considered in the 1 cycle, followed by the depth in the 10 cycle. The 100 cycle moved through both width and depth to cover the whole focus. A more elaborate description of the approach for each cycle can be seen below in Figure 7. Each cycle iterated back and forth between the main project question, research and design aspects, and the conclusion.

| 2.3.2 Design roadmapping

The desire of NS for this project was to create a future roadmap towards fully circular trains. Another requirement from my IPD education profile was that a design concept should be created in order to confirm my design skills. In order to combine these two, the design roadmapping method was used. A roadmap is a visual portray of design innovation elements plotted on a timeline (Simonse, Hultink, & Buijs, 2015). It enables organisations and designers to devise creative responses to future strategic challenges, while providing strong visualisation and decision making support (Kim, 2016). The roadmapping approach used in this project ran along the guidelines described in the book 'Design Roadmapping' (Simonse, 2017). Below, the analysis steps from this approach are listed, together with how they have been applied within this project.

| 1. Trend research

Trend research relies on uniting bits and pieces of mixed media into a trend creation that imagines future value. The trend research method used in this project approaches the trend patterns approach.

| 2. Future vision

The future vision creates an expression on a desirable future. In this project, I combined the plans for the Train of the Future with a discussion with employees of the NS sustainability department as input for creating a future vision.

| 3. System breakdown

In the system breakdown, a technical breakdown into parts was constructed first. Then, the parts were clustered in multiple ways to gain more insight into the meaning and implications of the parts. This was also used as input to turn the future vision into more concrete steps.

| 4. Design pacing

With the design pacing analysis, the focus is shifted back into the historical timeline to see how various aspects have developed over time. This pacing was used in comparison to validate the pacing of the future roadmap.

| 5. Value mapping

Within value mapping, the trends of the future are turned into drivers to and vision statements to further shape the future vision. I found that in my project, there was an overlap between the Future vision and the Value mapping steps.

| 6. Roadmapping

The roadmap is the final product of the method. It is a visual overview, showing all the analysis done before and the conclusions drawn from there. It sets a future vision to aim for, and all the steps to take along the way. For my project. I combined the traditional roadmap with the train and material flows at NS.

Within design roadmapping, concept design can be used in order to illustrate, investigate or confirm this future vision. The nature of this method implies that the product will be positioned more towards the future, and, depending on the product positioning, might remain more conceptual instead of an embodied design.

| 2.3.3 Co-reflection/reflective practice

When working in an iterative process, it is important to reflect to ensure that the insights that are gained are integrated back into the project. For this, I used a combination of co-reflection and individual reflection, as described in Figure 9. The benefit of the 1:10:100 method is that it creates moments for reflection quite early in the process, which helps to scope the project. Other moments that I used for reflection were my midterm and greenlight meeting, both of which took place in the third iteration.

The co-reflection of the first and second iteration cycle were performed separately with my NS mentor and my TU Delft IDE mentor and chair. Ideally, these co-reflections would have been performed with all project stakeholders together, but busy schedules and the limitations of the Corona virus made this difficult to realize. These co-reflections were conducted by presenting my work thus far in an online meeting, and noting down the comments. Afterwards, I personally reflected on my work and the comments, and decided on the course of action for the next iteration or phase.

There were multiple co-reflections in the third phase. The midterm co-reflection was performed similarly to the first and second iteration co-reflection, and the green light reflection was performed with the NS and IDE mentors and chair together. In addition, before the green light meeting an additional co-reflection was carried out with colleagues of the NS sustainability department. These colleagues were not as involved with the project, which allowed them to consider the project in an unbiased manner. Additionally, although all colleagues had affinity with sustainability, they all had a different background and role within the company, which led to new angles, new insights and new contacts and leads.

In addition to the co-reflection cycles, there was also validation of analyses and conclusions by discussing my work with NS and industry experts in online meetings.

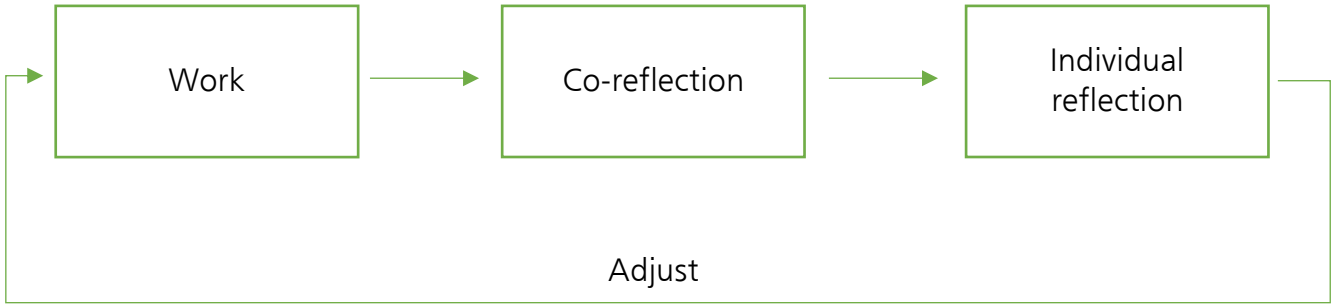


Figure 9: Co-reflective practice

3 CYCLE 1: PRESSURE COOKER

This chapter presents the main findings for the project in the first iteration, which had a time span of 1 day. The cycle process and all the results can be found in Appendix A.

3.1 FINDING WIDTH

"Where, when and how can research and design make an impact?"

As the project scope was very broad, the first cycle was aimed at finding the width for the project focus. This was done by doing a pressure cooker of the whole project in the first day, in order to find interesting topics and knowledge gaps.

"What is the potential of the chosen design methods?"

Additionally, the pressure cooker approach gave me the opportunity to quickly test the chosen design methods without focusing too much on the results. This allows me to estimate how useful the methods are and in what way they can contribute to the project.

In the first iteration cycle, I gathered insights and information along the whole project scope by collecting existing data and lessons learned from current NS projects. The figures on the next page show a few examples of the results. Figure 10 shows the first sketch for train outflow, Figure 11 explores a possible future scenario for fully circular trains, and Figure 12 shows a concept design. The most important iteration insights and answers to the research questions are listed in Table 1.

Table 1: Research, design and methodology insights from the first iteration cycle

 **Research**	From the research, I uncovered that there is not much known on the materials used in most train types. Additionally, it is important to get a better understanding of the train of the future, and thus the future design context. This will help to focus my design in such a way that it fits the train of the future as well as contributing to achieving fully circular trains.
 **Design**	My design focus for this cycle was to find a repurpose application for used train materials. And although this is an actual and difficult design challenge, I found it was not where I want to focus on within this project. Instead, I want to create a structural change to prevent waste at the end-of-life, as this is where design can make an impact.
 **Method**	The 1:10:100 method allowed me to keep a focus on the whole project and the expected results, and prevented me from dwelling too much on one subject. This way, I could better decide where I want to put my focus during the rest of the project. For the design roadmapping, I felt I still lacked experience on how to apply the methodology. Still, I think there is potential in this tool for finding interesting research directions and analyses, and to present results visually.

The co-reflection indicated to focus more on the future design context instead of on current practice. The designed concepts were considered a nice discussion topic, but not likely to be carried out after I finished the project. However, the value of this iteration was mainly to find direction in the project. Both parties were interested in the combination of material flows, roadmapping and concept design.

3.2 FINDING DEPTH IN THE NEXT ITERATION

In the next iteration, I want to work out the knowledge gaps in a more detailed manner. I want to do this by constructing a detailed material data overview for a specific train type and performing a more elaborate trend research. Additionally, I want to shift my design focus to the front of the train lifecycle and prevent non-recyclable waste materials.

Regarding methodology, I found the 1:10:100 method very useful to keep my focus on the whole project, and I will keep this method to shape my following iterations. Design roadmapping also looks a promising method to combine both roadmapping and design, and in the next iteration I want to further look into this method to see what elements are useful and where they fit within the project.

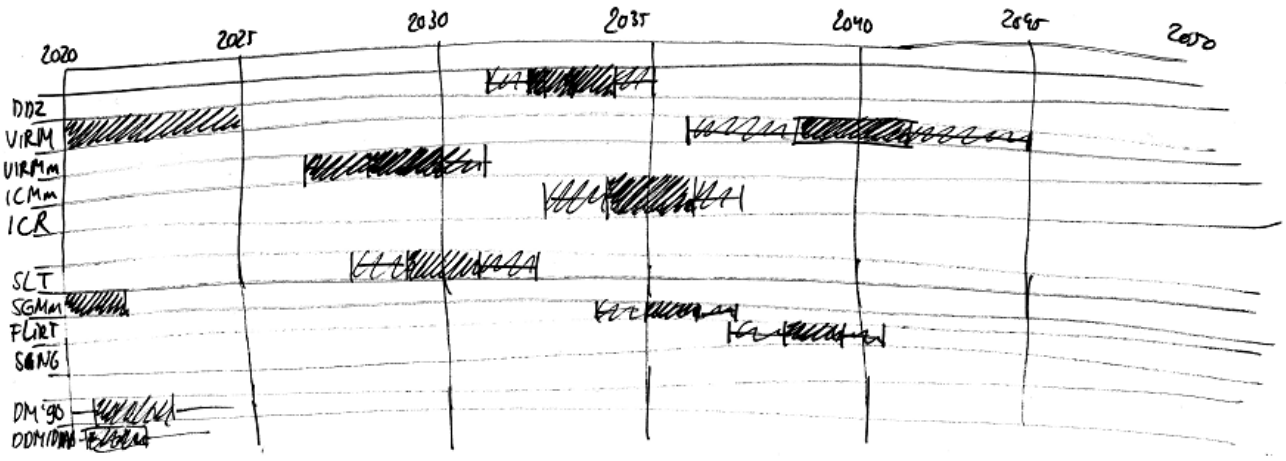


Figure 10: First sketch of train in-/outflow

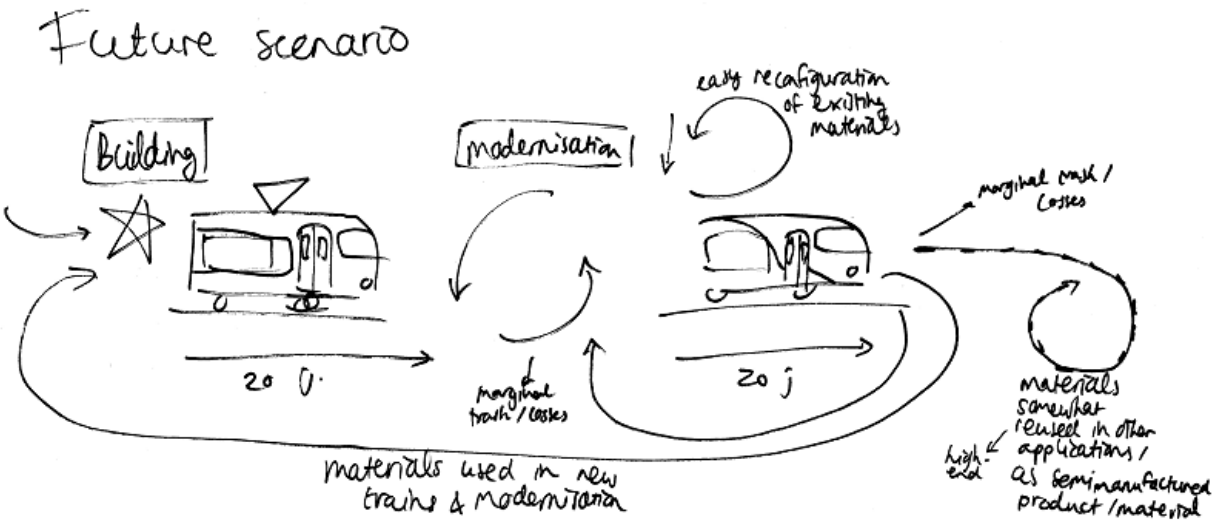


Figure 11: First vision of future scenario for fully circular trains

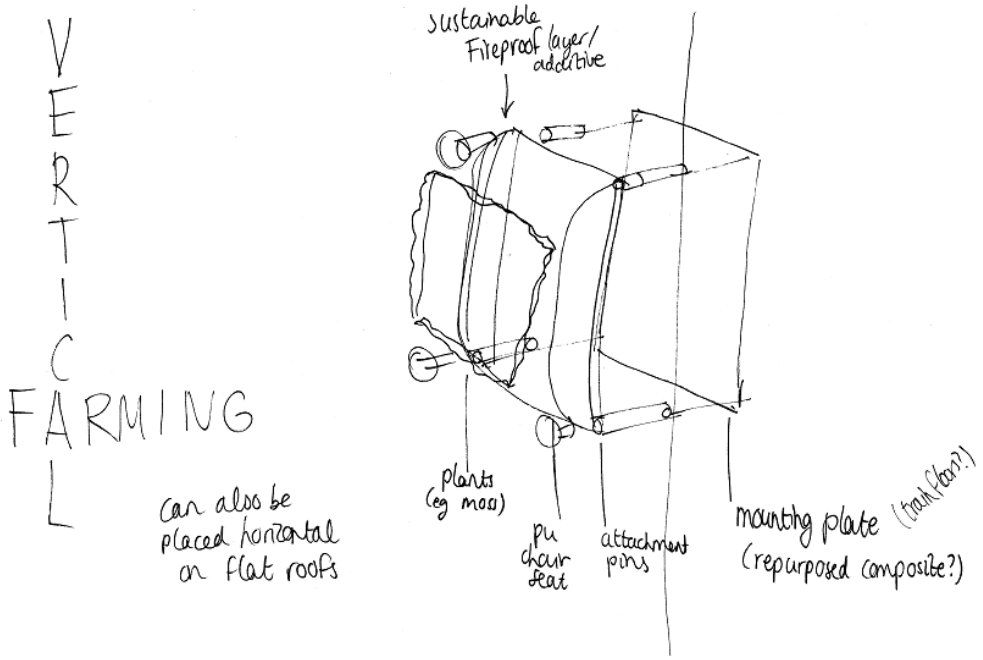


Figure 12: The Vertical Farming concept that repurposes used train seat foam as a plant growing medium for buildings

4 CYCLE 10: DEEP DIVE

This chapter presents the main findings for the project in the second iteration cycle, which had a time span of 10 days. The cycle process and all the results can be found in Appendix B.

4.1 FINDING DEPTH

> *"What level of detail yields the best results?"*

Even though the project width has been established in the first iteration cycle, not all topics can be worked out in the same level of detail. Therefore, this iteration will determine what level of detail best balances efficiency and results for the chosen research activities to determine the depth of the project scope.

> *"How can 1:10:100 and Design Roadmapping help to inspire and focus research and design activities?"*

The previous iteration determined that the 1:10:100 and Design Roadmapping were both valuable methods. This iteration will go more in-depth to find out what contribution the methods can make on inspiring and focusing the project.

In the second iteration cycle, I worked out the selected research directions in a more detailed way. Also, a higher level of visual quality was used to make it easier to share and discuss the results with others. On the next page, Figure 13 and Figure 14 show the concepts of this iteration. The most important iteration insights and answers to the research questions are listed in Table 2.

Table 2: Research, design and methodology insights from the second iteration cycle

 **Research**	During this iteration cycle it was shown that spending more time on an analysis does not improve the results in a linear manner. However, I found what worked and didn't work for certain analyses: Creating a train data overview helped me to gain more insight into the material streams and quantify these streams, but it took quite a lot of time to create a detailed overview, even with a head start.
 **Design**	This iteration cycle spend more time on elaborating the design vision by listing some sustainable design practices that I found interesting. This sparked some concept design visions, mainly aimed at designing products aimed at a second product lifecycle. However, due to the superficial approach, the design vision is not applicable outside my own context. This indicates that the needed level of detail is highly context-specific.
 **Method**	The 1:10:100 approach helps to focus by giving only limited time to try out different directions. The Design Roadmapping has not been applied yet in this iteration, but studying the method gave as insight that the steps can be used to choose and structure the research and design activities.

The co-reflection gave me the insight that material overview created was insightful, but that it lacked information on how the materials are interconnected. The trend research should also be specified more towards trains and NS, instead of general topics such as mobility. For the design vision, it is important to make the distinction between product function and technological design approach and to consider the roadblocks that are encountered along the way.

4.2 ANSWERING THE MAIN RESEARCH QUESTIONS THE NEXT ITERATION

In the next iteration I want to validate and elaborate on the analyses thus far. Still, I need to keep in mind to balance my activities and not to get stuck on a single aspect, such as documenting train materials. Additionally, I need to focus more on the design instead of research and spend more time on concept design and roadmapping.

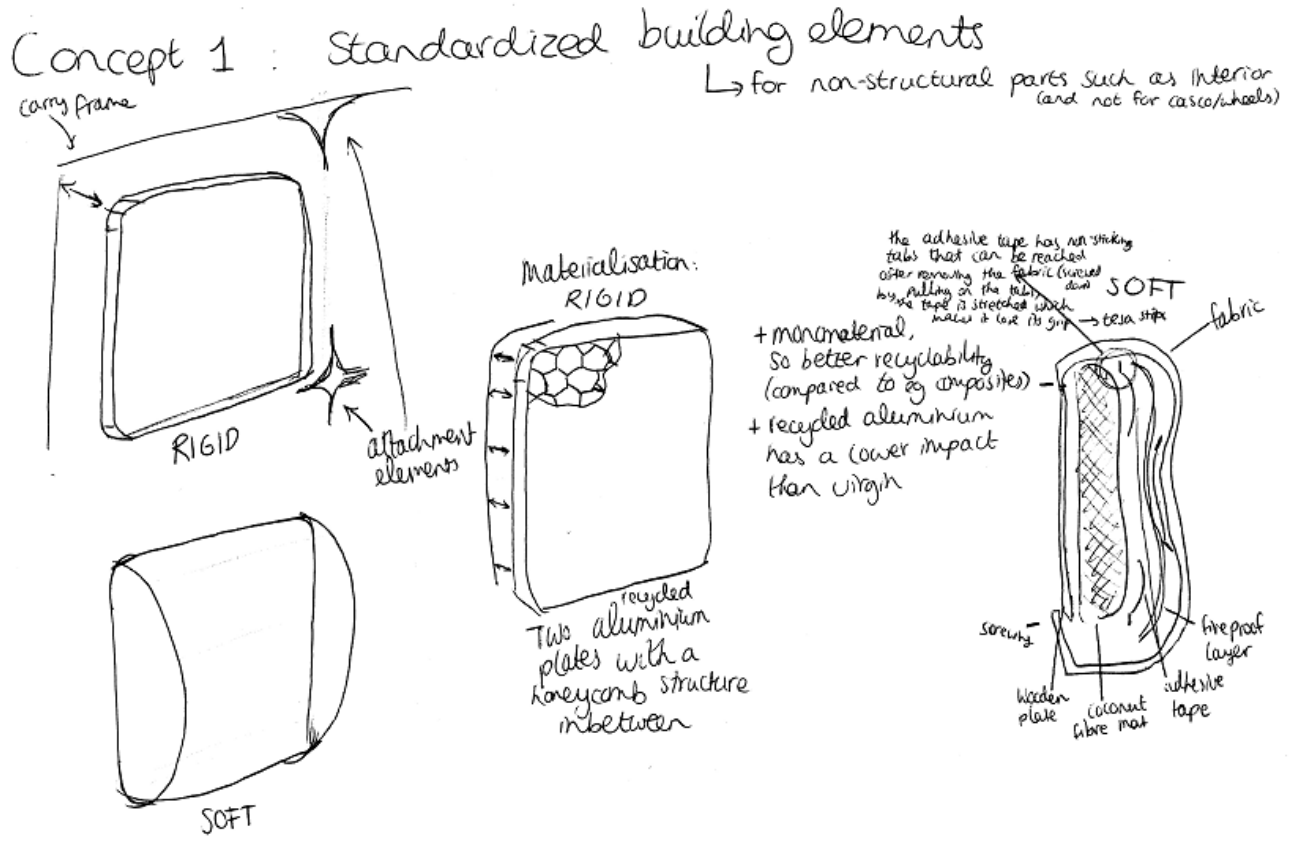


Figure 13: Concept 1; Standardized building elements (soft and rigid) for use within all non-structural parts such as interior

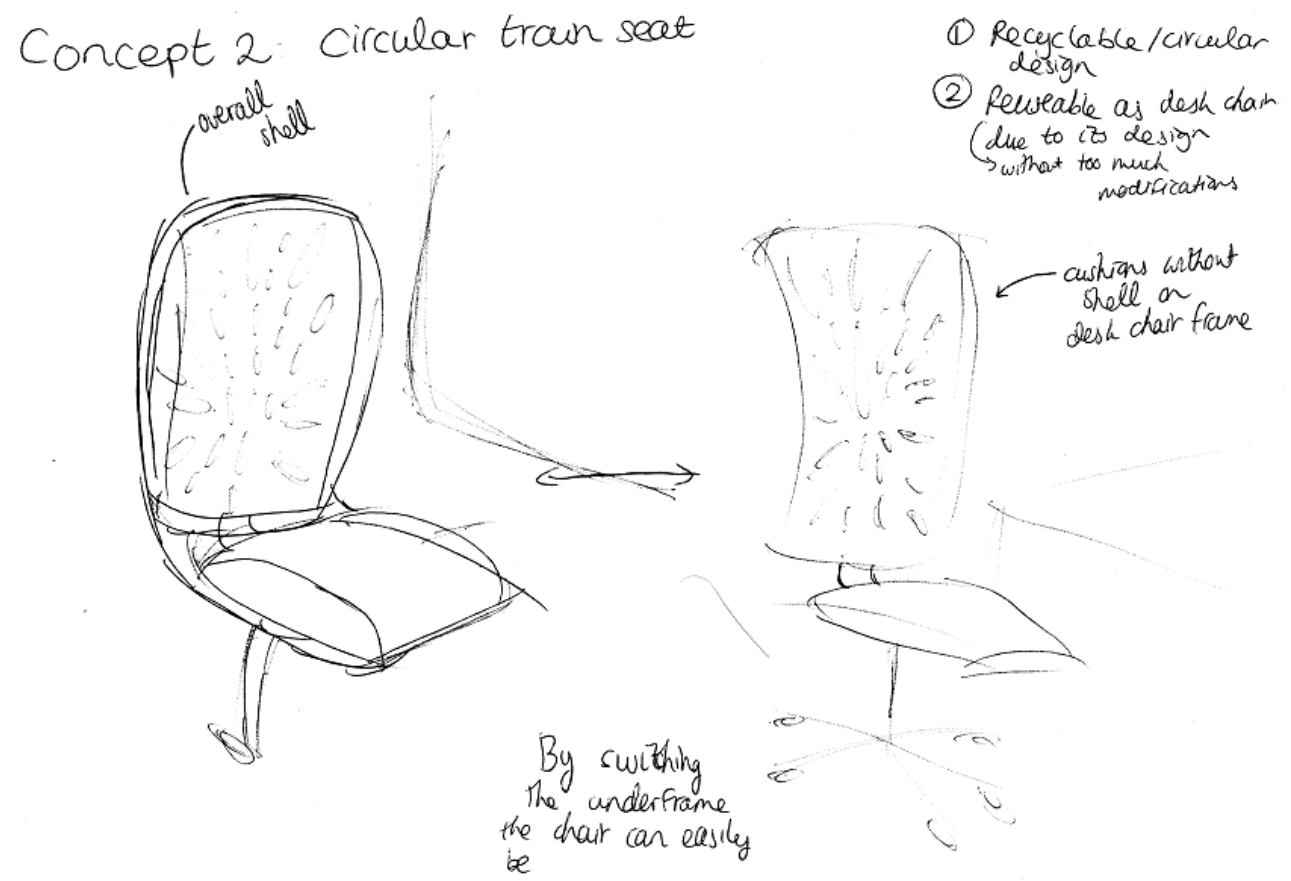


Figure 14: Concept 2; A circular train seat which has a recyclable/circular design and is designed for reuse as desk chair

5 CYCLE 100: LONG RUN

This chapter presents the main findings for the project in the third and final iteration, which had a timespan of roughly 55 days. The whole process and all the results can be found in Appendix C.

5.1 ANSWERING THE RESEARCH QUESTIONS

> *"How can NS achieve circular inflow and outflow during building, modernisation and end-of-life for the train interior, car body and bogies?"*

This third iteration cycle is the longest cycle, and focuses on the main research and design question. All time after this iteration cycle will be aimed at working out the final concept and report.

> *"How can design methodology be used to structure a complex design project?"*

After running the project for the full length, a conclusive answer can be given on how design methodology, and more specifically 1:10:100 and Design Roadmapping, can contribute to structure a complex design project such as this one.

In the third iteration cycle, I continued along the same lines as the second iteration cycle. I validated the results I had so far, and made additional analyses. This led to the final concept design direction. In the next paragraphs, the most important analysis results and concepts of this cycle are presented. The most important iteration insights and answers to the research questions are listed in Table 3.

Table 3: Research, design and methodology insights from the third iteration cycle

 **Research**	The material flow research gave a quantified representation of the non-recyclable material flow for the coming years. This is a good starting point when looking where to focus design efforts. The train part cluster can be used to see which parts could be tackled with the same approach. An important sidenote from the timeline research is that changes within train interior design often happen slowly.
 **Design**	The research inspired me to think of the non-recyclable train parts of the VIRM modernisation, more specifically chairs and side walls, as inspiration for my concept design. This inspiration shows that although current practice and issues shouldn't have the focus, they can still serve as inspiration to know what problems need to be avoided in the future.
 **Method**	Having design methods to fall back onto is really helpful when working on large open-ended design projects. I felt that 1:10:100 was most useful for determining project scope. Although I did not finish the roadmap, I felt that Design Roadmapping was still of use in this project. It helped me to keep a focus on the future design context instead of focusing on current practice, and the method steps served as an inspiration to shape my research and design activities.

The co-reflection of this cycle was more extensive, and helped to shape the future design vision, and to validate my chosen design direction. For example, a helpful comment in confirming my concept direction was that the train chairs already receive Additionally, it reminded me to also validate my work up till now, and I received useful feedback and contacts for further working out the concept design.

5.2 FINISHING THE CONCEPT DESIGN

The next phase is not a research and design iteration, but serves to work out the chosen concept direction into a concept design. The configuration options for this design will be explored to come to a final concept recommendation. This concept can be worked out further in future NS projects such as the sustainable train material handbook, or serve as inspiration for finding sustainable alternatives for non-recyclable materials such as glass fibre composite.

6 MOST IMPORTANT RESEARCH INSIGHTS

6.1 TRAIN FLOW 2020-2050

In this analysis, the train flow was quantified and visualised, as shown in Figure 15. It includes the inflow, outflow and modernisation phase for all current NS trains. The data up to 2020 has been determined through use of internal documentation. The dates after that have been estimated and validated with Pieter van Halem of the Network Organization (NO) department of NS (Personal communication, 2020, July 16).
In Figure 15 there can be seen that most train series will have to modernised and dismantled in a circular way if NS wants to be fully circular from 2030 on. At the moment, NS already achieves about 99% circularity for modernisation (86,2% within and 12,6% outside the train) and about 94-95% recyclability for end-of-life trains. However, the remaining percentages prove to be the most tricky, as these are mainly mixed materials with no standard circular processing method in place. This means that tailored solutions need to be found for each material type. As materials are often not well documented and often vary across train series, this will cost a lot of effort.

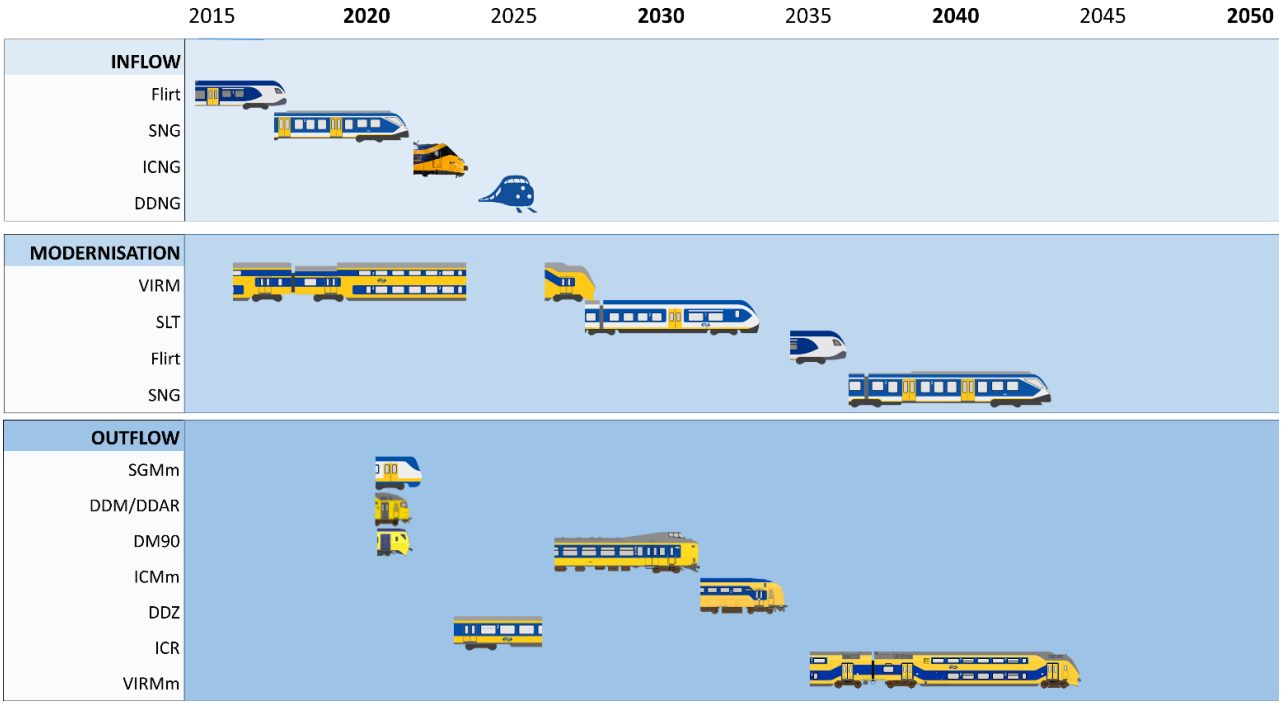


Figure 15: Overview showing train inflow, modernisation and outflow

6.2 MATERIAL FLOW OVERVIEW

The previous iteration near-completed a material analysis of the SGMm sprinter train. Although this was insightful, it took a lot of time to construct, even with a rough indication of materials and weights as starting point. It was therefore not feasible to perform similar analyses for other train series. Therefore, the flow analysis was expanded by processing the material data reports for the VIRM double decker intercity train and the SLT sprinter train. These train series were selected purely on the basis that this was the only available information. A more complete picture of the material flow between now and 2030 would have been achieved by adding the ICMm and ICRm trains, as these are relative large train series with low sales potential. The material analysis for the VIRM made use of internal Circular IQ material reports (commissioned by NS) for the VIRM1 and VIRMm1, and a reuse/recycle/dispose overview for the VIRM modernisation. These datasets were 100% complete. The material analysis for the SLT made use of a data overview provided by Bombardier, the manufacturer of the train. This gave about 57% of the total weight, but it missed the weight of the bogies. The weight of the bogies was averaged on 35% for the SGM sprinter, so using the same weight percentage, a material flow of about 90-95% accuracy could be constructed for the SLT.

The final material flow, shown in Figure 16, is constructed by combining material flows with the number of trains found in the train flow analysis. In this figure, the recyclable material weights are shown as positive, and the non-recyclable material flows as negative. Not all material types were available for all train types; for example, no elastomers were reported for VIRM, even though there is rubber around the windows. Still, Figure 16 gives a good first estimate of the material flows between 2020-2030.

Figure 16 shows that even though the SLT is not corrected yet for material reuse during modernisation, the amount of non-recyclable material is almost negligible compared to the recyclable material flow. This is mainly due to the high weight percentage of metals due to the heavy car body and bogies, and the low weight of non-recyclable materials such as glass fibre composites. To put it into perspective, VIRM is 79% metals, SLT around 82%, and SGM an estimated 65%. The weight percentages of composites in the train however are between 4-7%, while this material makes up the largest share of the non-recyclable material stream. An important side note here is that weight percentages can be misleading. Weight does not say anything about the absolute sustainable impact of these fractions, such as for critical materials in electronics for example. Therefore, it is important to look beyond weight when selecting focus for impactful sustainable change.

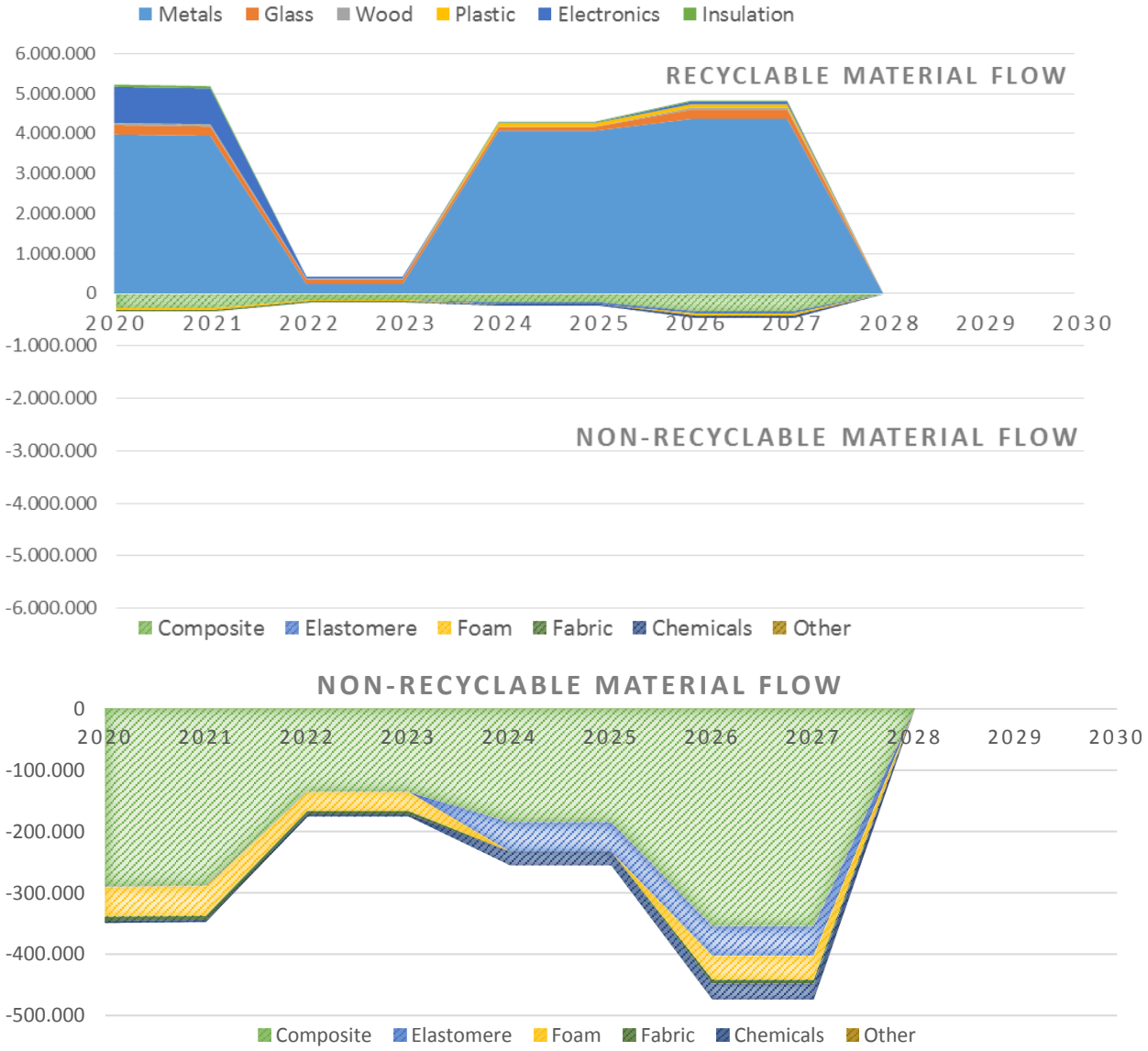


Figure 16: Overall and non-recyclable material outflow 2020-2030 for SGM outflow, VIRM modernisation (corrected for material reuse in modernised train) and SLT modernisation (not corrected for material reuse in modernised train)

6.3 SLOW DEVELOPMENT OF TRAIN INTERIOR

The historical timeline, an excerpt of which can be seen in Figure 17, shows that train interior has changed very little over time. Change is mostly very subtle and focused on materialisation, such as the lighter/thinner chairs, use of composites. And even then, change is quite slow. According to Biron , composites have been used in trains since around 1960. However, the first NS train to use composites stems from 1994. This is a 30-40 year difference, in which at least four new train series were built.

Figure 17: Transition of train interior between 1874-2017

Interesting to see is that parallels can be drawn between the new interior concept by Gispen and theantique train interior. Figure 18 shows the interior design for the train of the future on the left, and the interiors of trains from 1874 and 1908 on the right. Of course the whole look and feel of the train is different, but elements such as the vaulted ceiling beams and half-high benches can already be found in trains dating back as far as 1874. It is therefore not surprising that Gispen concept manager Sarah Schiffer mentions in an interview with Spoorpro that they looked at historical interior designs (Kruidhof, 2018). Remarkably enough, the half-high benches were first introduced to limit the amount of lamps needed for one carriage: not only frugal, but also sustainable!

Figure 18: Design concept for the train of the future, compared to the interiors of trains from 1874 and 1908.

6.4 INTERCONNECTION CONSUMER DESIGN AND SUSTAINABILITY TRENDS

A large amount of trends were gathered again on the topic of design, corporate strategy, consumer behaviour and sustainability, using various trend reports as found in Appendix F. These trends were then clustered and laid out in a web pattern, as shown in Figure 19. The pattern web shows the interconnections between trends, which contribute to the two main themes in Design and Sustainability, which are "Design around people's needs" and "Circular Rethink". Most trends found within this trend analysis can be referred as a contributor or consequence of these trends. On the right, two additional themes are indicated, which act as boundary conditions for the execution of the two main themes.

The most interesting insight from this figure is that there is hardly any connection between Designing around people's needs and Circular Rethink. This could explain why design for sustainable change is mainly driven by NS, instead of originating from the industry and/or consumer requests.

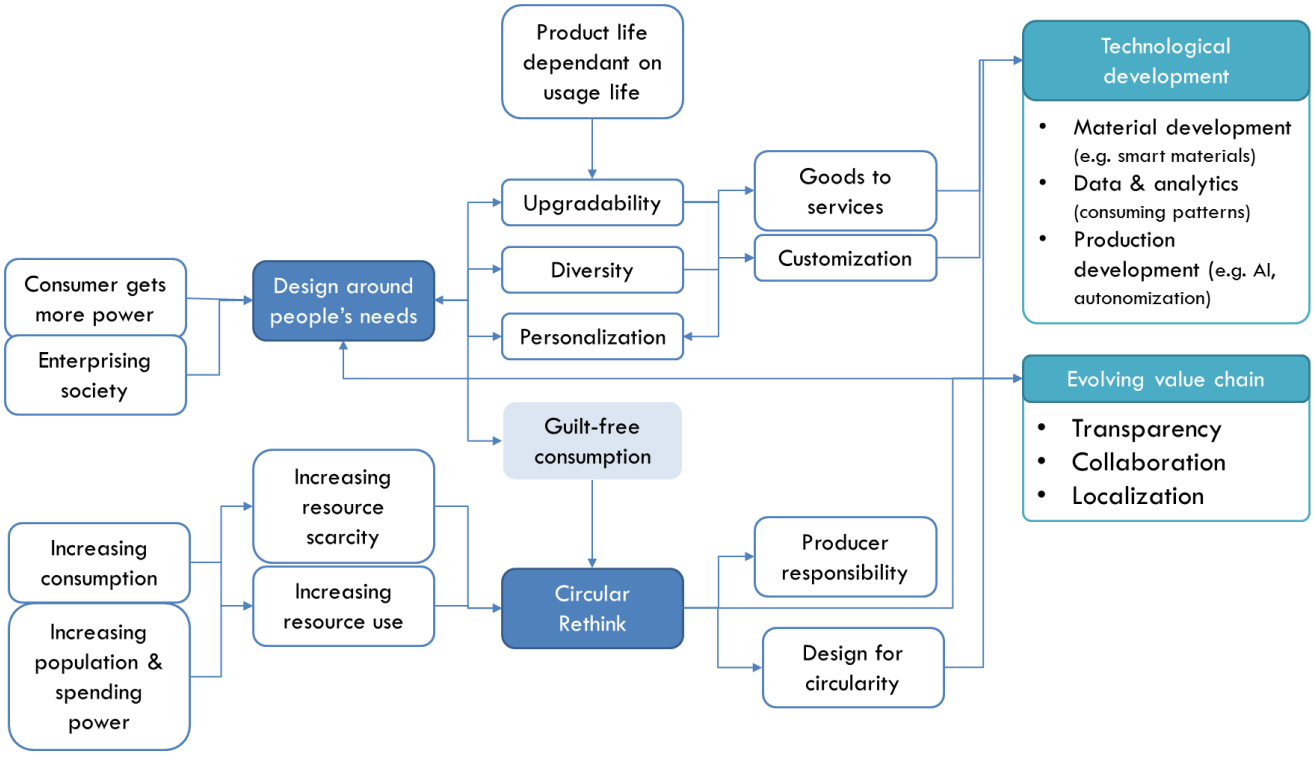


Figure 19: Design strategy and sustainability trend pattern web

6.5 CIRCULAR ROADBLOCKS

There have been many circularity roadblocks mentioned through the report, such as the missing knowledge on material data and the tender obligation of NS. To structure the findings and summarize all known circularity roadblocks, the topic was discussed with Ilse de Vos van Eekeren, circularity expert at NS. Through her job, de Vos van Eekeren has a lot of experience with working on circularity projects and all the roadblocks involved. The roadblocks from the discussion were clustered and plotted along the train lifecycle (building – modernisation – end-of-life). This shows what the main roadblock themes are, and whether roadblocks apply to certain lifecycle phases or to the entire train lifecycle.

The final roadblock map can be seen in Figure 20. The found themes are Safety, Legislation, System, Design and Costs. Most themes are found in the System and Design clusters. However, the impact of each roadblock varies. For example, although there are not many different roadblocks within Safety, this is one of the most important roadblocks. This roadblock maps could be improved by also rating the impact or indicating the level of obstruction for each roadblock.

When considering the distribution of the roadblocks, it can be seen that most roadblocks are valid for the whole train lifecycle. However, these roadblocks might be encountered at different moments in time, and then it might be too late to change the origin of the problem. By presenting the roadblocks in an overview and considering them beforehand, even before the train is build, a large part of the roadblocks could be avoided. The remaining roadblocks require more structural change in for example company culture or company strategy.

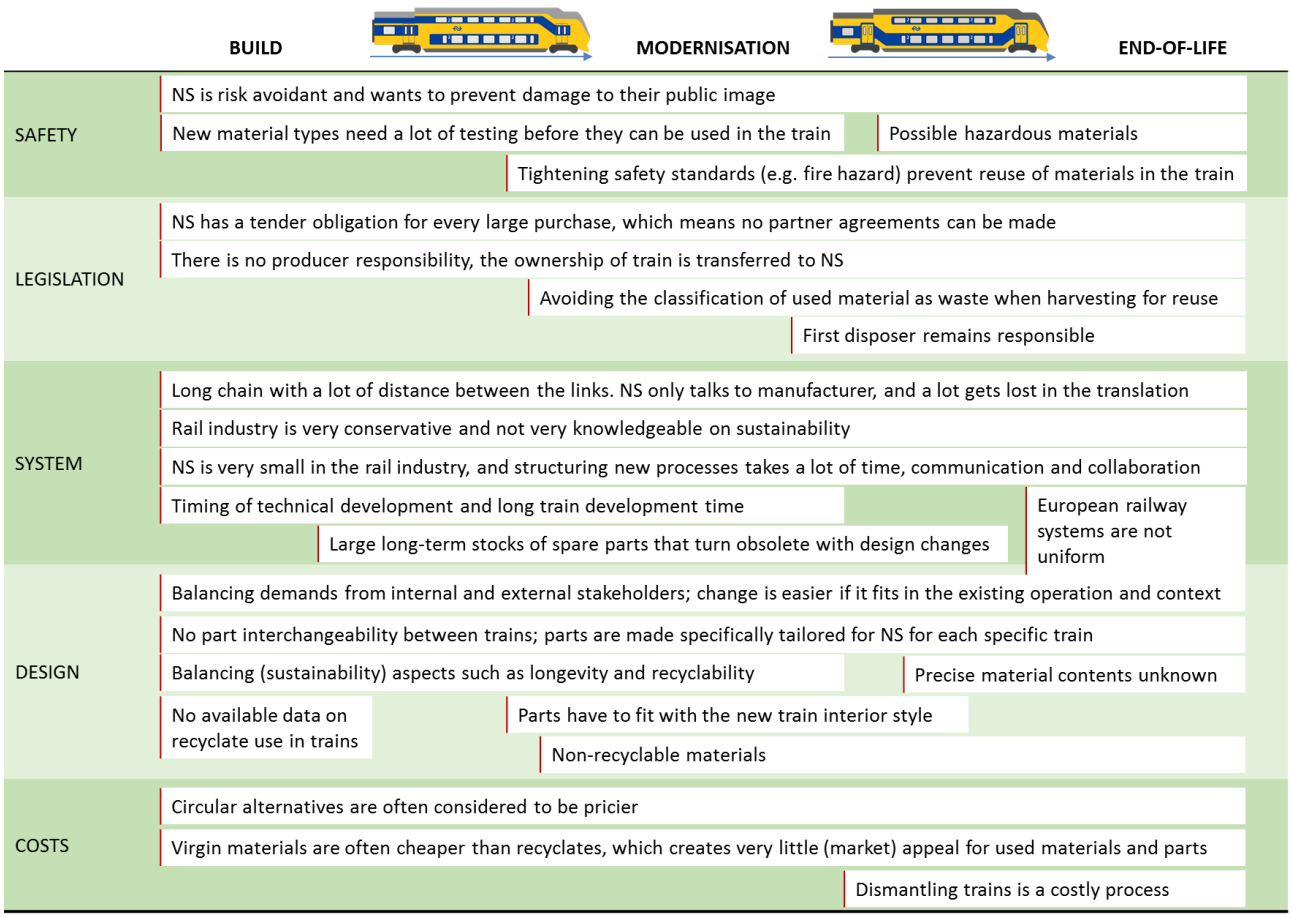


Figure 20: Roadblock map plotted against train lifecycle. Roadblocks validated with Ilse de Vos van Eekeren.

7 MOST IMPORTANT DESIGN INSIGHTS

7.1 SUSTAINABLE DESIGN VISION

The future design vision was constructed in two-fold manner: firstly by investigating the design for the train of the future, and secondly by discussing with the members of the sustainability department what their desirable vision for the future is. When comparing these, the former is much more concrete and feasible compared to the latter. Therefore, the train of the future was applied as short-term vision and the discussion as a long-term vision. Below, the visions are described in more detail.

Short term (2030)
The new train interior (visualised in Figure 21) is comfortable, welcoming, accessible, and facilitates a wide range of activities. Within the design vision, two main themes can be discovered, as described below. On the whole, the first theme describes how the interior modules are shaped and applied to increase the traveling experience and raise customer satisfaction, whereas the second theme describes how these modules are created to realize a dynamic and circular train.

Figure 21: Concept interior for the train of the future (Mecanoo and Gispen, 2018).

| 1. Travel time becomes your own time
Train interior has mainly been focused on creating seating capacity (Schiffer, 2018a). However, the train of the future should be more than a tube that transports you from A to B. It should be a comfortable place where you feel at home and where you can spend your time how you like it (Arne Lijbers, 2018). As the way people like to spend their travel time varies, a pallet of interior elements has been created based on analysis of activities and train traveller profiles (NS, n.d.). These have been combined into twelve interior modules, grouped into three different train zones: the relaxation zone, concentration zone and social zone. Each zone has its own interior and place within the train, based on activities and travel duration. For example, the social zone has 'stitting' places (in between standing in sitting) and is closer to the door, as it is aimed at shorter journeys. The concentration zone is located deeper into the train, as it is aimed at longer train journeys (Schiffer, 2018a). This creates a dynamic travel landscape with different sit, 'stit' and standing places, where every traveller can find their ideal place, depending on activity, travel duration, travelling party size, luggage and required facilities (Mecanoo, 2019).

| 2. The train of the future is modular and circular
The design of the interior elements is based on a modular system which enables adjustability and variety per train car (NS, n.d.). By using a modular grid, the use of the available space can be optimized and the modules can be fit into the train like building blocks. The modules are suitable for every train type, and can be combined to give travellers more space in rush hour and a space to suit their demands outside rush hour (Schiffer, 2018b). The elements are fully circular, fabrics are reusable resources, and modules are easy to disassemble and interchange. This way, the train can respond to the demands of travellers and is prepared for the sustainable mobility of the future (Mecanoo, 2019). By designing in a modular and circular way, the concept is timeless and universal. Developing circular elements also increases product longevity and prevents waste (Veenendaal, 2018).

Long term (2050)
The discussion with the employees of the sustainability department yielded a wide variety of insights and visions. These insights were clustered into the following general themes described below. The derived themes are along the same lines as the themes of the short-term vision. However, the themes of the short-term vision mainly describe the envisioned change within the train interior, while the long-term vision also describes the envisioned systematic operation of the train of future.

| 1. The train of the future is personalized
The train of the future connects to the traveller by offering seamless transitions along the door-to-door journey. It integrates alternative transport methods where possible to offer the best possible journey. The journey planner is updated to provide advice not only based on the journey but also on other important aspects such as speed, comfort and sustainability.

| 2. The train of the future is an experience
The train of the future should not only allow people to spend their time how they want it, but create an experience. This ensures that the train of the future can compete with the rising competition, Think for example about socialising or exercising in the train, or involving aspects outside the train, such as sightseeing in scenic areas. The traveller can enter the relevant train car/area based on their desires. In addition to the train, the station and station area can also be involved, such as creating green stations in car-free inner cities, as space efficiency is a strong argument for the train.

| 1. The train of the future is efficient
The train of the future makes not only efficient use of the available space, but also of the system. It works through the swarming of smaller units in a demand-driven system. Through the integration of smart technology, trains can run in much shorter intervals. This approach helps to reduce the amount of trains needed and optimize the seat occupancy in and out of rush hour.

Figure 22 gives an idea of how such a system could look like. In the upper right corner, the personalized travel planner allows customers to tailor their journey from home, and show more insight into the desires for specific journeys. Over time, the train cars will decrease in size and adopt a swarming approach, sending the parts of the trains only to the desired destinations, instead of occupying the whole length of the train to the end destination. The train cars will also have different styles, similar to the train zones of the short term vision. Think for example speed cars with high seating capacity, or comfort cars with working facilities. The swarming approach will allow quick transition between car types to meet demands, for example deploying more speed cars in rush hour and more comfort cars outside rush hour. The modular train interior will also allow to quickly reconfigure car types to fit seasonal or shifting demands.

7.2 FINAL CONCEPT IDEAS

Figure 23 shows the final concept ideas that were created in the third iteration as explained below. Concept 2 was chosen as final concept after discussion with my mentors and NS colleagues. The main argument here was that the design of the train seat is already a focus point for NS, with a whole design team already working on further developing this element. The design of the side wall however has not been considered much, so there is still a lot to gain here.

| 1. Circular train seat: This concept is a reconfiguration of the standardized building element concept from the previous iteration cycle. It explores how one modular element could be built up from a single element shape, shaping blocks and a frame, thus reducing the amount of parts. The materialisation of the elements should also be circular, such as by replacing the PU foam with latex foam, which is made from a natural resource, compostable, and far more durable.

| 2. Circular side wall panel: This concept is a circular reconfiguration of the current wall panel in the train. It replaces the current non-recyclable composite material with honeycomb core sandwich material, which is a mono-material and thus much easier to recycle. Additionally, this material could be combined with the reversible tape used in train floors to increase the sustainability.

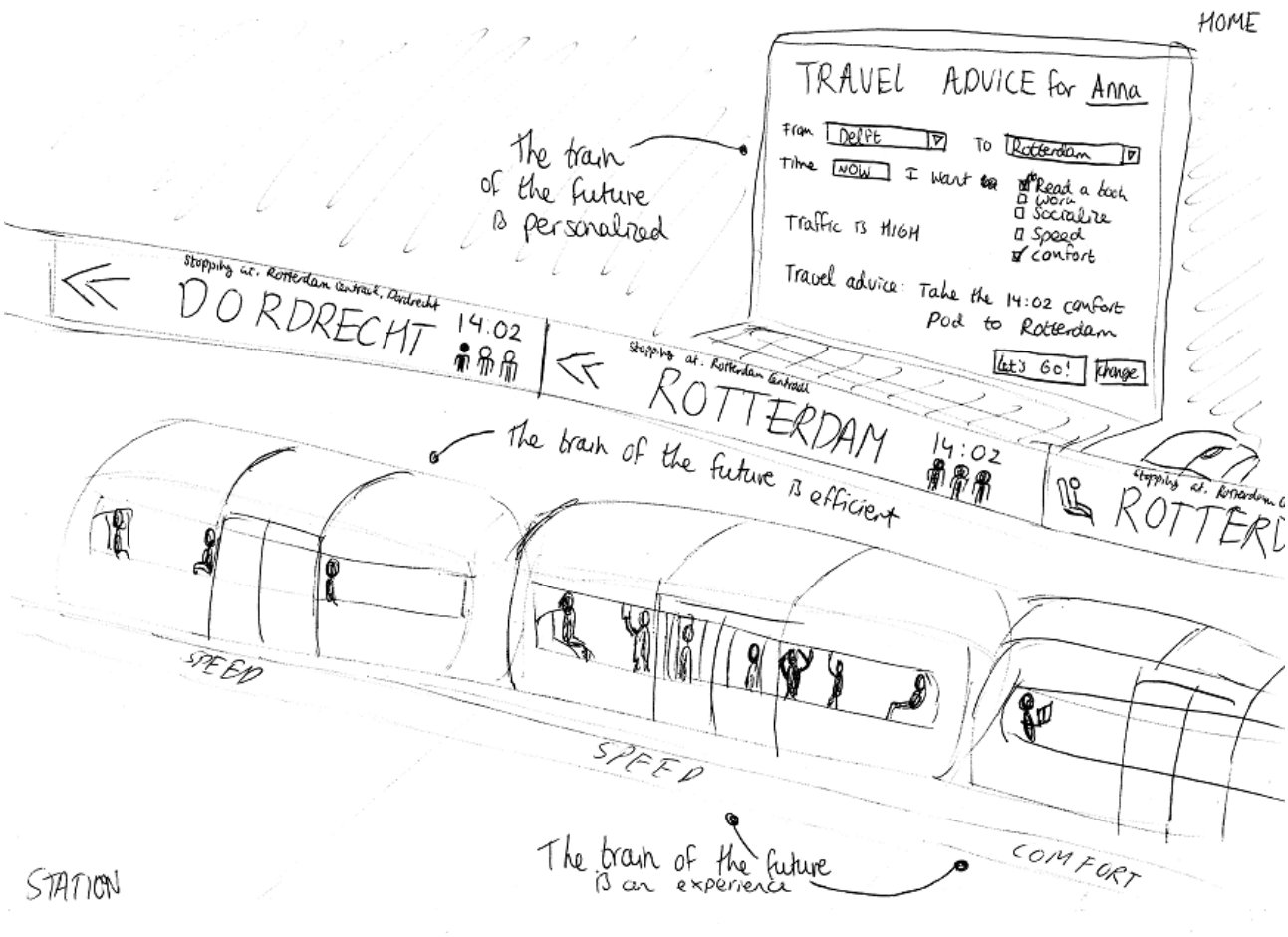


Figure 22: System concept vision constructed through interviews with NS employees

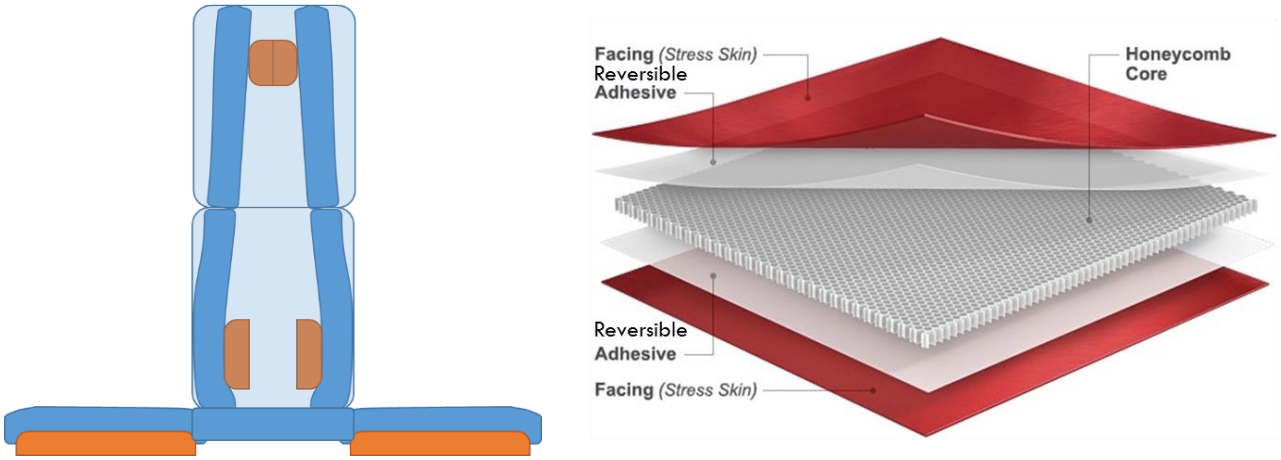


Figure 23: Quick visualisations of the final concept ideas

8 DESIGNING A CIRCULAR INTERIOR SIDE WALL PANEL

This chapter discusses the concept design for a sustainable interior side wall panel. It first explains the current side wall design, followed by the design proposal for a sustainable alternative.

8.1 CURRENT SIDE WALL PANEL

This paragraph will describe the current configuration of the side wall panels, as well as their issues regarding circularity. This will illustrate why a circular alternative is needed and what changes need to be made in order to achieve a more circular construction.

8.1.1 Design for single use

The current side wall panels are designed specifically for NS, and tailored for the specific train type. The side wall panels since VIRM-1 in 1994 are made from a composite material of thermoset polyester resin with glass fibre reinforcement. Composite material is created by embedding the reinforcement fibres into the resin matrix (Royal Society of Chemistry, 2015). Glass fibre composite is a lightweight yet sturdy material, and it becomes fire retardant with the right additives. This makes it an ideal material for use in the train, and creates a long product life for the panels.

The usage scenario for the current side wall panel is shown in Figure 24. It shows how the wall panel moves through its lifecycle from begin to end of life, which takes around 15-20 years.

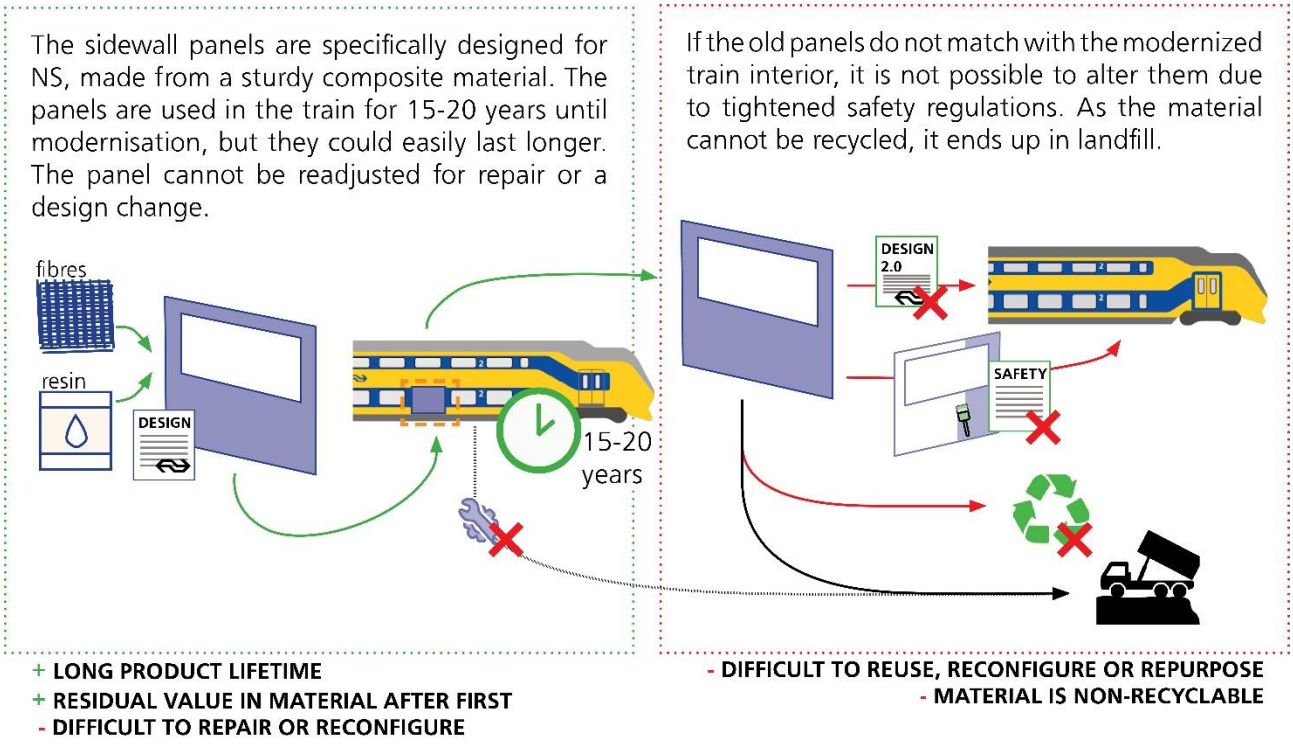


Figure 24: Usage scenario of the current side wall panel

After this first use cycle, the material has enough residual value to consider a second use cycle. This could be reuse in the train or repurpose outside the train. This second use cycle, however, is difficult to realize. At the modernisation the train interior is renewed, and the old panels might not match with this new design. For example, at the VIRM-1 modernisation, the panels could not be reused as they had the wrong colour. Reconfiguring the panels means that they need to comply with the new safety regulations, such as fire safety. These regulations have tightened in the 15-20 years since the panels have been designed, which makes it very likely that the old panels will not be approved. Repurposing the panels outside the train is also challenging, as the panels have a very specific shape and reshaping the thermoset material is not feasible.

| 8.1.2 Design for disposal

As the panel cannot be reused or repurposed in any way, it will reach its end-of-life at the modernisation. At the moment, the composite panels are trashed and moved to landfill. Considering the Ladder van Lansink, recycling should be the only option here, but this is difficult for composite materials as the fibres are deeply embedded into the resin. It is not yet feasible to recycle the material or its resources on a large scale in such a way that it can be reused in the same application. Especially for glass fibre composites, the glass fibres are damaged too much in the process, and virgin glass fibre is far too cheap for the low-grade recycled fibres to be able to compete. Often when "recycling" composite, the material is burnt or shredded, and the residue is used as filler in other materials. This means a lot of the material value is lost, which means it not a circular option (Van Oudheusden, 2019). Of course, recycling processes can still develop over time, but composite materials have already been around for a long time. Therefore, waiting for this change to happen does not fit the frontrunner position that NS wants to take in the circular economy. A (recyclable) circular alternative is needed instead.

8.2 PROPOSED ALTERNATIVE: HONEYCOMB PANELS

One possibility to construct a circular side wall panel is to use a sandwich material with a honeycomb core. This material is, similarly to composite material, lightweight yet strong. However, honeycomb core panels can be constructed from mono-materials, which makes it much easier to recycle.

| 8.2.1 Honeycomb construction

Honeycomb panels are created by sandwiching a honeycomb core between two plates or skins, as shown in Figure 25. The geometry of the core varies, but they all possess a layer of hollow cells (mostly hexagonal) between thin vertical walls. This construction allows for lightweight honeycomb structures with substantial structural strength (GlobalSpec, 2020). Other benefits for honeycomb panels are continued performance after failure, efficient sound and energy absorption, and for plastic honeycombs also good chemical and moisture resistance (Plascore, Inc., 2018). As the used materials do not mix but remain separate layers, it could be a more sustainable alternative to fibre-matrix composites, if the panel is constructed in a reversible manner. The next chapter will elaborate on how a sustainable and demountable panel could be created.

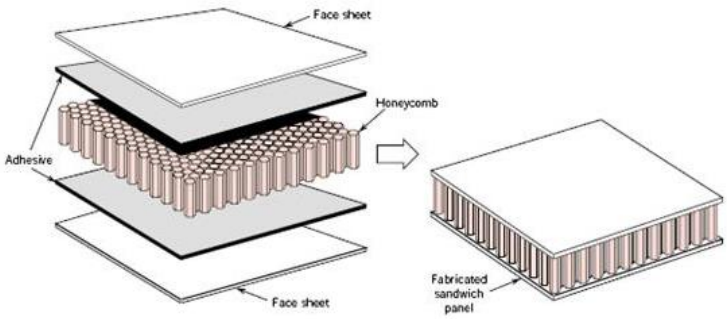


Figure 25: Honeycomb panel construction. Retrieved from GlobalSpec (2020).

Most metal honeycombs are created through the stacking method shown in Figure 26. Adhesive lines are printed on foil sheets, which are stacked and pressed into blocks. The blocks are then cut into slices, which are expanded into honeycomb cores (Corex Honeycomb, 2020). For plastic honeycomb, a continuous production process has been developed, shown in Figure 27. During this process, a extruded film is thermoformed and folded to create a honeycomb core (Pflug, Vangrimde, Verpoest, Bratfisch, & Vandepitte, 2003).

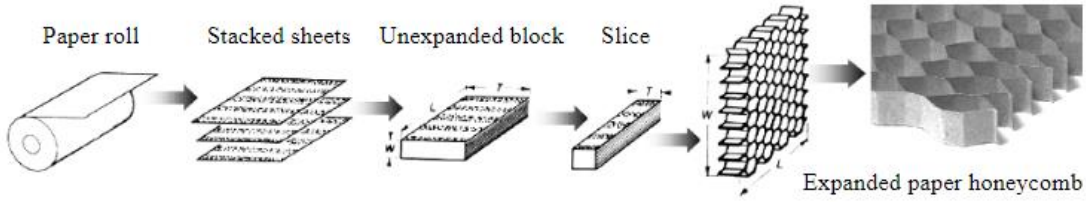


Figure 26: Creating expanded honeycomb cores through sheet stacking. Retrieved from Pflug et al. (2003)

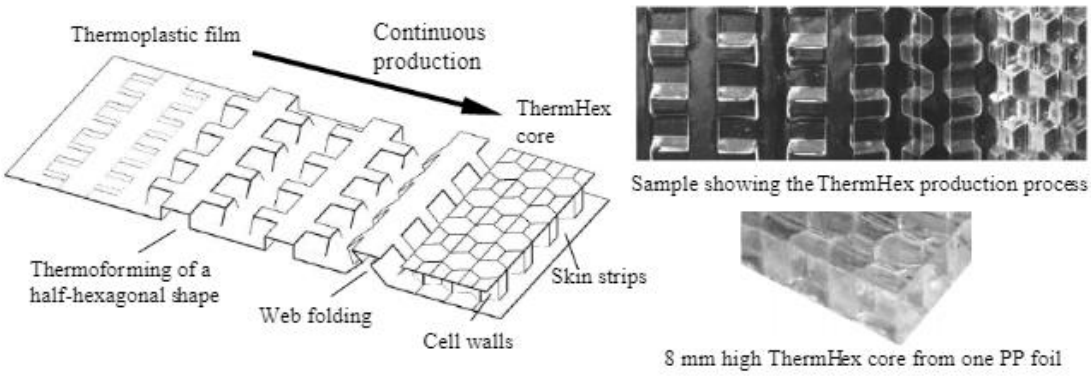


Figure 27: Continuous honeycomb core production. Retrieved from Pflug et al. (2003)

| 8.2.2 Railway approved

EN 45545-2 describes the tests that need to be carried out to ensure that a material is safe for use in trains. When passing the test, the material can be approved for a specific vehicle safety class, which are Hazard Level (HL) 1,2 and 3. These levels are based on how long the trains spend in tunnels and whether they have sleeper trains, where HL3 is the strictest level (DGE - Smart Specialty Chemicals, 2020). This report researched the materials produced by a number of European manufacturers. For aluminium, the honeycombs of four out of six manufacturers are EN45545 approved, of which three at HL3 level and the fourth not reporting a specific level. The two manufacturers that do not report on EN45545 however, do state that they have materials in use in the railway industry. For the plastic honeycombs, three out of four manufacturers mention application of the material in the railway sector and/or train interior, but do not offer any concrete examples. On the other hand, Econcore reports in their rPET material sheet that the material is normally inflammable (building material class B2 DIN 4102-1, respectively D according to EU classification), and that higher grades of fire resistance can be obtained in sandwich elements when using specialized skin materials.

8.3 DESIGN PROPOSAL FOR A SUSTAINABLE SIDE WALL PANEL

This chapter will elaborate on the proposed design for a sustainable side wall panel, discussing the configuration, usage scenario and implementation roadmap. The design considerations are discussed in Appendix D, and the full list of design criteria can be found in Appendix E.

| 8.3.1 Panel configuration

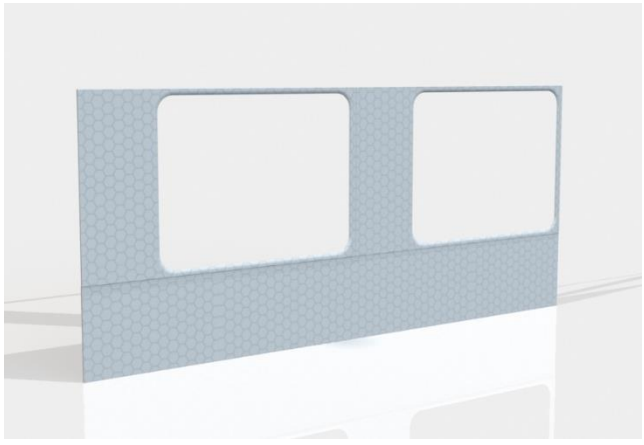


Figure 28: Render of the sustainable side wall panel

For the panel configuration the materialisation, construction, shape and finish options have been investigated. The chosen options are shown and argued in Table 4. This gave the panel shown in Figure 28. Figure 30 shows an exploded view of the panel, indicating the design decisions regarding the shape. The first indicative measurements for the panel are shown in Figure 32. These measurements were constructed based on the SGMm layout, in combination with creating measurements that are multiples of each other and that optimize the available panel space in order to improve reusability.

Figure 29 shows a more detailed view of the different material layers. Due to the reversible adhesive and the removable foil, all layers can be separated again. Regarding the foil, one of the remarks for designing a sustainable side wall panel is that it is not as visible to consumers as, say, a train chair. Therefore, attention could be drawn to the

side panels by using a foil with a recognizable pattern, such as the honeycomb pattern shown in Figure 31. This way, NS can draw attention to the walls in their communication with travellers, such as: "Have you seen the new honeycomb pattern in the train? Did you know that these walls can be completely disassembled and recycled again after use? Just one of the many ways in which we make our trains more sustainable"

Table 4: Most important design decisions for the sustainable side wall panel

Material: Aluminium

Even though aluminium is more expensive, it is already tested and certified for use within the railway industry. Additionally, aluminium is inherently fire resistant, which means that the panels are not disqualified when they need to be reconfigured at the modernisation. Both aspects saves costs, offsetting the increased material price. Using plastics (e.g. PP or rPET) is also an option, but these would need additional fire retardants.

Shape: Flat

A flat shape is easier to reshape, making it easier to reuse in other trains or other repurpose applications. By placing the window off-centre and separating the bottom partition, more usable space is created. Additionally, this means that when the panel is reused in a different train series with a different window shape, only the window section needs to be adjusted or replaced.

Adhesive: Niaga (reversible)

Niaga is an adhesive that can be reversed when applying heat. This means that the skin could be replaced in case it gets damaged. Additionally, Niaga is non-flammable and recyclable. Additional research and testing is needed to get Niaga certified for railway use.

Finish: foil

Foil is easier to apply and works without harmful chemicals. It is also fire resistant, easier to clean, has a longer lifespan and keeps its colour better and for longer. At the end of life, the foil can be removed and recycled. Additional research and testing is needed to get the foil certified, but as the material and adhesive underneath are both fireproof, this is highly likely.

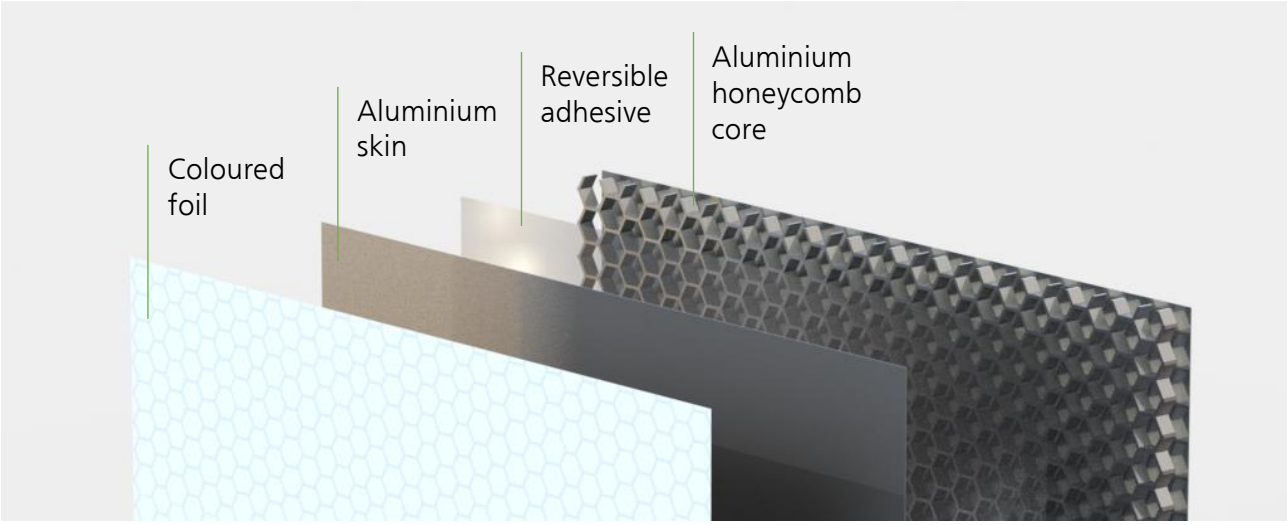


Figure 29: Material composition in exploded view

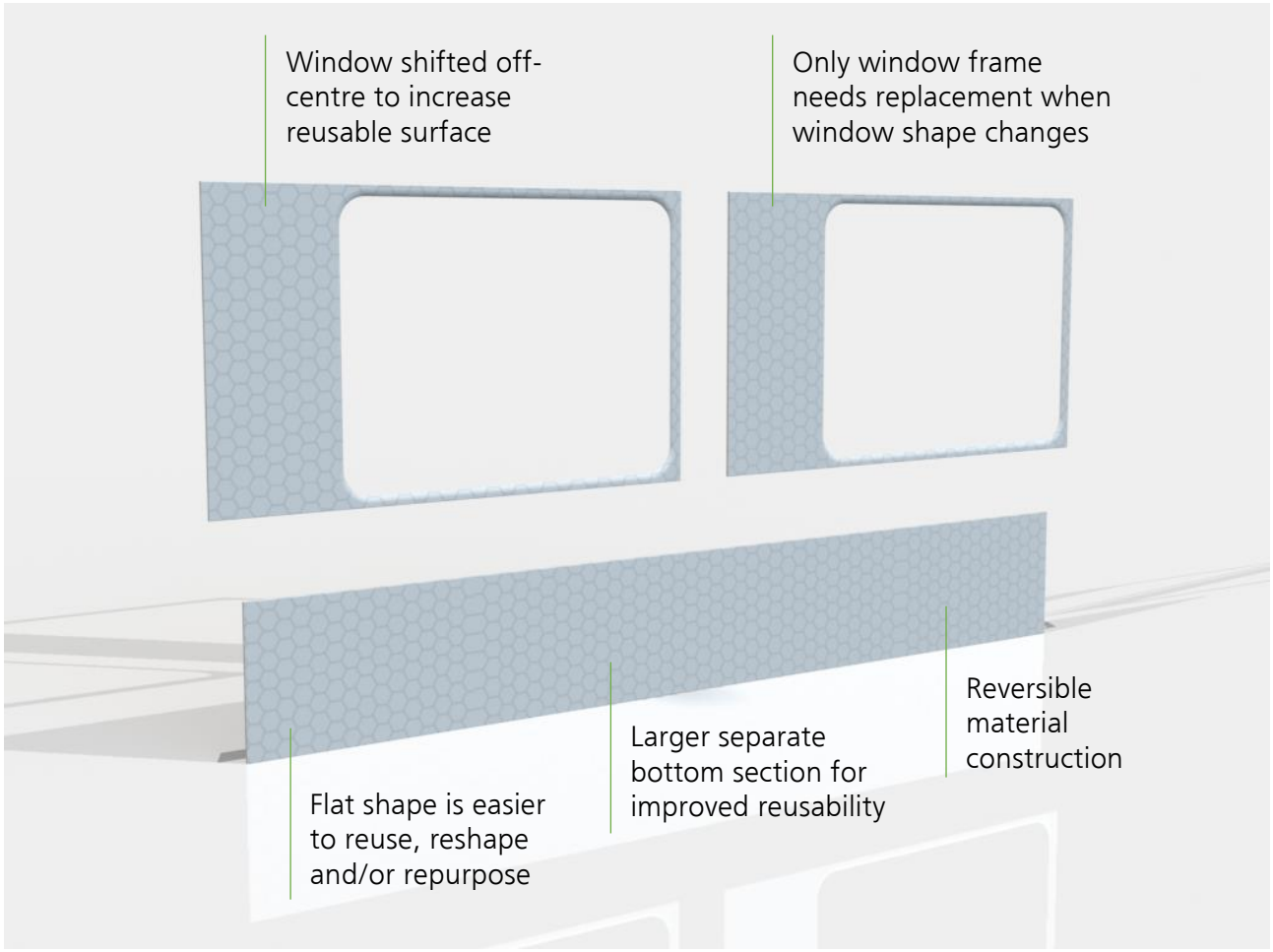


Figure 30: Shape configuration and its benefits

Figure 31: Honeycomb pattern to print on the finishing foil to increase recognisability of the sustainable side wall

Figure 32: First measurement indications

| 8.3.2 Design for reuse

Figure 33 shows a possible usage scenario for the designed honeycomb side wall panel. As opposed to the composite side wall panel, the honeycomb panel can be reconfigured. This allows the panel to fit the new design of the train when it gets modernised, leading to an increased product lifetime. Additionally, it improves the reusability of the panel in repurpose applications.

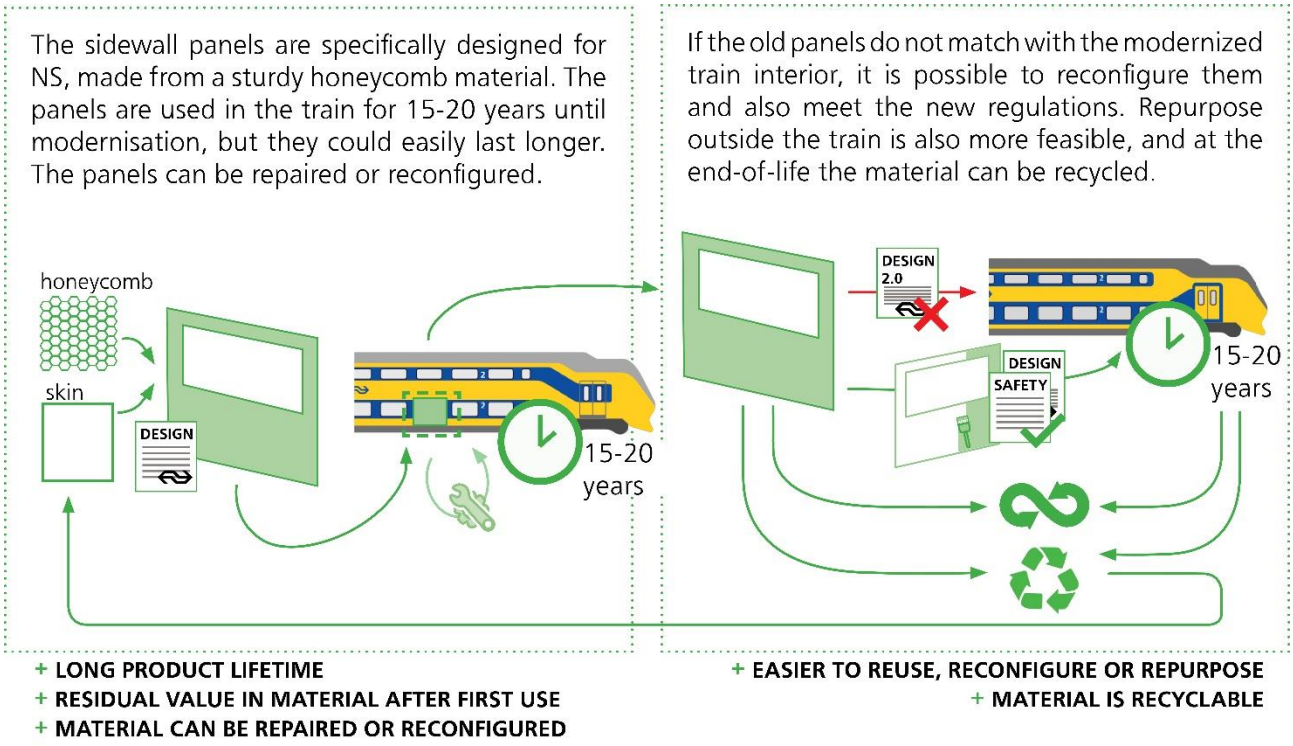


Figure 33: Possible usage scenario of a honeycomb side wall panel.

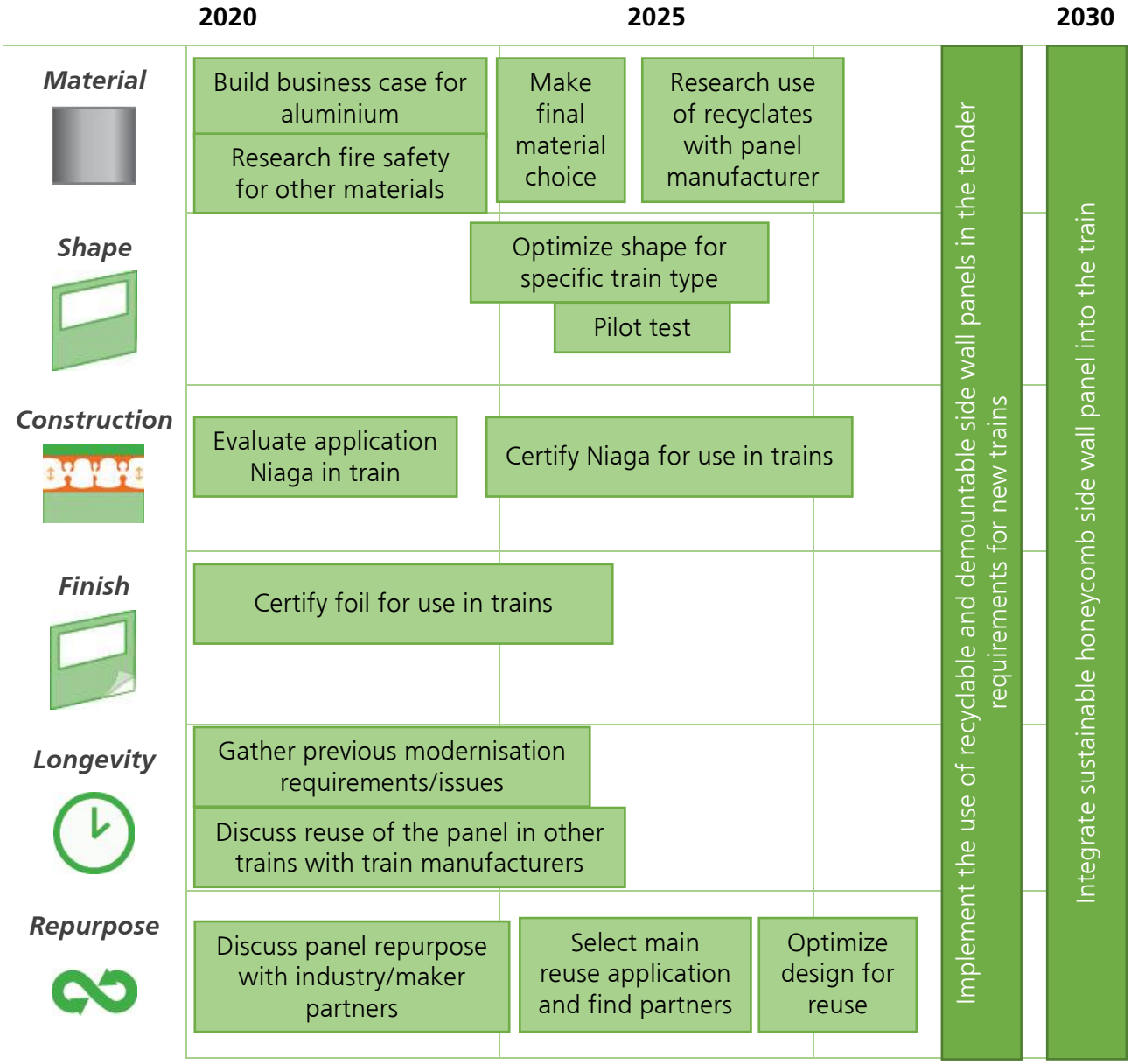
Multiple repurpose options were investigated. Reusing the panels in other train series would be the preferred solution, but this might not be possible due to the tender obligation of NS. The construction industry could also be considered, with the availability of the material as the main attention point: if a guarantee of delivery on a sufficient scale cannot be realized, the panels are per definition not suitable for reuse in the construction industry (Alex Verkuijlen, New Horizons Urban Mining, Personal communication, 2020, July 16). Other applications could be to use the material to make furniture. The bottom sections of the panels is not wide enough to create an adult desktop, but children's desks, side tables, closets or bookcases could be an option.

At the end-life-phase, the panel can be recycled instead of ending up in landfill. The use of removable foil and reversible Niaga adhesive mean that all product constituents can be separated to yield only mono-materials, which enables easier recycling. It is still preferable however to create a panel that limits the amount of different materials used.

| 8.3.3 Product implementation roadmap

The roadmap shown in Table 5 describes the actions and milestones needed to reconfigure the current side wall panel into a circular panel. This design can be developed further in future NS projects, or serve as input or inspiration for the NS circular material handbook for train tenders.

Table 5: Development steps needed before the panel can be implemented



9 CONCLUSION

The main research and design question of this report was "How can NS achieve circular inflow and outflow during building, modernisation and end-of-life for the train interior, car body and bogies?" The initial plan was to construct a roadmap towards sustainable change, and to develop a sustainable design concept. Due to time constraints, the roadmap has not been completed, but the analyses derived from the Design Roadmapping method could serve as a starting point. The sustainable design concept that was developed shows how NS could construct a fully circular side wall panel. Besides further developing the panel itself, the sub-elements or insights themselves are also useful. These could serve as input for developing a sustainable material handbook to inform train manufacturers on sustainable alternatives during train tenders.

The main methodology research question was "How can design methodology be used to structure a complex design project?" I found that the 1:10:100 method was very useful to quickly determine a project scope but it lacked structure within the '100' cycle. The midterm and green light deadlines were very useful to "force" reflection halfway and near the end of the iteration cycle. Still, I should have transitioned towards concept design earlier than at the green light meeting point to allow for more design iterations. In the future, I would integrate more iterations within the '100' cycle. I also applied Design Roadmapping, and even though I did not complete the final roadmap, I still found this method very useful. The method helped to structure my research, especially at the beginning, and to inspire new analysis directions. Additionally, the method helped me to keep focus on the future instead of focusing too much on current practice. Focusing on the future meant my first concept iterations were not very feasible, but it kept me aimed at innovation and helped me to keep an open mind, which sparked the final concept design. And although not all elements in this concept design are futuristic or innovative, the combination of the different elements is new.

10 RECOMMENDATIONS

Regarding research, I would recommend to expand the material overview further, such as by including the material data for the ICMm train series. Additionally, the material flow should not only indicate weight percentages, but also the sustainability impact. This helps to prioritise future actions. It also helps to set a standard to perform material analysis so all trains are processed in the same manner. NS is looking at implementing the Circular IQ tool for this. I think this is a good move, but I still think it is important to not only look at the material list but also at the interconnectedness of the materials. Just a list of materials does not say anything about how materials or parts can be dismantled, even within a certain material type. The train breakdown analysis, not discussed in the main report but found in Appendix C, made a start on this. This analysis also yielded a collection of clusters of train parts. I think that it can be useful to link these clusters to certain sustainability strategies, such as linking the more rigid/deeply buried technical parts to design for longevity, and the more superficial and fashionable parts such as interior to design for modularity. For the concept design, the most important step is to set up a business case to see if the extended lifetime and improved fire safety of aluminium honeycomb panels weighs up against the increased price. The most important consideration that NS needs to make here is whether they prefer price or fire safety. From my experience, NS is a risk-avoidant company which a very strict fire safety approach, which is why I chose the aluminium honeycomb, but this choice could be reconsidered. Additionally, not all aspects of the concept have to be implemented all at once. It is also possible to integrate parts of it, or slowly introduce the panel changes over time. For this, there needs to be prioritised which changes should be implemented or developed first. Finally, this project focused mainly on the train interior side wall panel. However, for a complete circular train, the other interior elements, the bogies and the car body should be studied as well to see how circular change such as the use of recyclates could be implemented. For example, Niaga commented that they would also be interested to see how a circular train seat could be created using their circular mattress technology. Presenting all these insights into a roadmap will help to focus and communicate priorities to internal and external stakeholders.

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A CYCLE 1: PRESSURE COOKER

This chapter presents the main findings for the project in the first iteration, which had a time span of 1 day. The main goal of this cycle was to explore the assignment and get a feel for the width of the assignment. This was also enforced through the timespan of this cycle: as it lasted only one day, there was no time for in-depth research. Instead, the whole project can be run through as a 'pressure cooker', which only looks into the different project aspects in a high over and quick-and-dirty manner.

A.1 3.1 FINDING WIDTH

> | *"Where, when and how can research and design make an impact?"*

As the project scope was very broad, the first cycle was aimed at finding the width for the project focus. This was done by doing a pressure cooker of the whole project in the first day, in order to find interesting topics and knowledge gaps.

> | *"What is the potential of the chosen design methods?"*

Additionally, the pressure cooker approach gave me the opportunity to quickly test the chosen design methods without focusing too much on the results. This allows me to estimate how useful the methods are and in what way they can contribute to the project.

A.2 RESEARCH

The research phase of this cycle consisted of four main analyses. Firstly, the definition of sustainability for NS was explored, followed by a brief trend analysis, an exploration of inflow and outflow of trains, and lastly documenting the lessons learned from other projects. These topics were chosen respectively to understand what sustainability means at NS, what the future context is, what train and material flows will have to be processed sustainably, and what can be learned from current and past projects.

| A.2.1 NS sustainability framework

As there are many different ways in which sustainability and circularity can be defined, this cycle started by writing down how these terms are defined for NS. This first definition was made by summarizing the results of a team day I attended where the new NS strategy for sustainable entrepreneurship was explored. To fit the future vision for NS, this new strategy would be a good starting point to adhere to.

Through this definition, NS divides sustainable mobility into three main themes: Climate neutral, Circular and Green. In the overall corporate strategy, social is part of the sustainable development, but this theme is not placed within the sustainability department. As my project was placed within the circularity theme, this definition was also noted down. This definition is based on the WBCSD definition for circular economy seen below. The main target is to be fully circular in 2030 (Personal communication, Ilse de Vos van Eekeren, 2020).

> *"The circular economy is an economic model that is regenerative by design. The goal is to retain the value of the circulating resources, products, parts and materials by creating a system with innovative business models that allow for long life, optimal (re)use, renewability, refurbishment, remanufacturing and recycling. By applying these principles, organizations can collaborate to design out waste, increase resource productivity and maintain resource use within planetary boundaries"*

| A.2.2 Future mobility context

The timespan for this cycle did not allow for in-depth trend analysis. Therefore, to sketch a quick context for this project, the NS strategy report was used to uncover the most relevant trends for NS. These were found and categorized through the DESTEP approach, as shown in Table 6. The trends in this overview mainly focus on mobility and the expected challenges and competition. NS will need to consider and overcome these in order to become futureproof.

Table 6: Trends uncovered from the NS strategy report

Aspect	Relevant trend
Demographic	Cities are becoming increasingly busier, whereas rural areas face shrinkage. The way in which we move around is crucial in this. Mobility will grow the coming decennia until 2040 with a maximum of 40%
Economic	The self-driving car can have an influence on the usage costs of multiple forms of mobility, including the train. *Expected increase of waste disposal costs (retrieved from personal communication)*
Political	In the climate accord package, agreements have been made to reduce the exhaust of greenhouse gases with 49% in 2030.
Ecological	We see the inclination for journeys within Europe below 700 kilometres in length to choose the much more sustainable train instead of the airplane.
Social	We have other demands regarding the availability of mobility. Being able to use and share a car, scooter, bike and even mopeds is more important than owning one. Travelers expect more and more a personalized door-to-door journey.
Technological	Electric traveling is winning terrain. Technological innovations make travelling more efficient and safer. We see new providers and forms of mobility. All forms of mobility are interconnected both physically and digitally. The autonomous, self-driving car is coming.

| A.2.3 Train flow from now to 2050

To get an idea what trains types and quantities would be flowing in and out between 2020-2050, an overview was made of the current NS trains. This overview was made by combining two different data sets. The first set consisted of a number of official outflow documents, provided by the train dismantling crew. This showed exact dates, but only covered the outflow in the coming few years. For the remaining timespan, a first estimate of the outflow timing was made by adding the average train lifespan (20 years) to the known build or modernisation dates of the train series. This gave the overview in Figure . The length of the outflow and inflow periods was estimated based on the number of train cars in each train series.

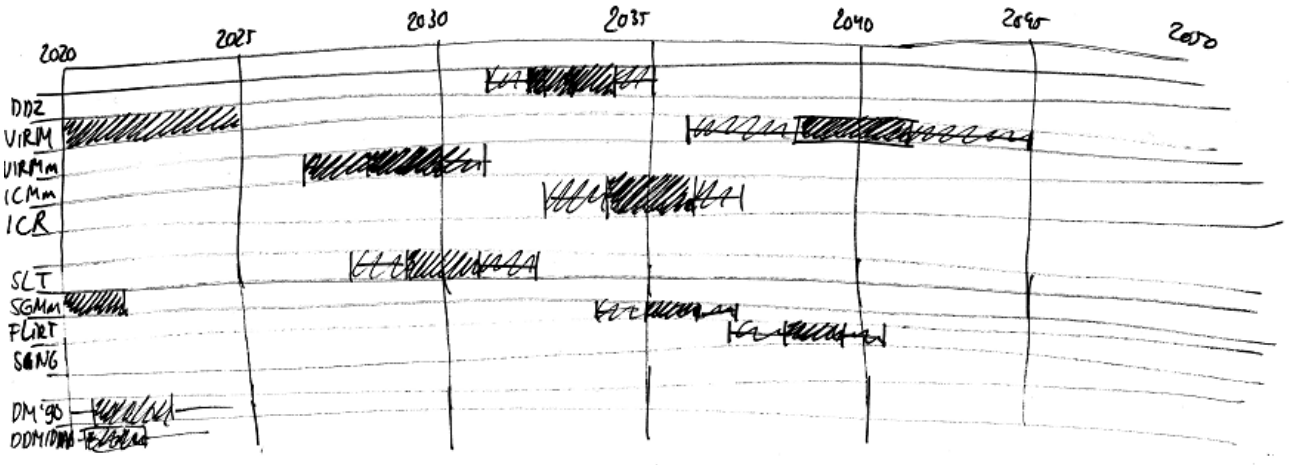


Figure 34: First rough sketch of the general train lifecycle and train in-/outflow

| A.2.4 Documenting sustainability lessons learned by NS

The wide range of activities linked to circular entrepreneurship at NS was also explored. The insights from these projects can be used to improve similar processes in the future or as inspiration for new improvements. First, a list of all relevant projects was constructed. This list was too long to be able to process all projects within this cycle, so instead the most interesting projects were chosen. This selection was based on my own experience with the projects during my previous internship period

before the start of my graduation. From here, I could judge the possible value of insights from each project, uncovering possible knowledge gaps that can be explored in the next cycle. The insights were gathered by brainstorming on the projects using a light version of the annotated portfolios method as described in Sauerwein, Bakker & Balkenende (2018). Within this method, a product is chosen as main focal point. Then, the relevant takeaways are listed, directly linked to the corresponding aspect of the focal point. In order to find patterns from these takeaways, the interconnections between the takeaways are drawn and dot size is increased according to the interconnections. The main themes for each project can be found from the patterns. Table 7 shows the list of relevant NS projects, with the selected annotation projects indicated in bold. Figure 35 gives an example of an annotated portfolio, here the portfolio for the VIRM modernisation.

Table 7: Overview of NS project linked to circular entrepreneurship

NS projects	
SGM harvesting	**Tender sustainability specifications**
VIRM modernisation	Eurospec project on sustainable train norms
Composite reuse in railway sleepers	Sustainable third party policy
Bicycle storage Eindhoven	Marjan Dessing
Sustainable AH to Go	LoopedGoods
Desks of train ceiling plates by Gispen	Omar Munie (terminated)
Challenges (Spoorlab, schools)	

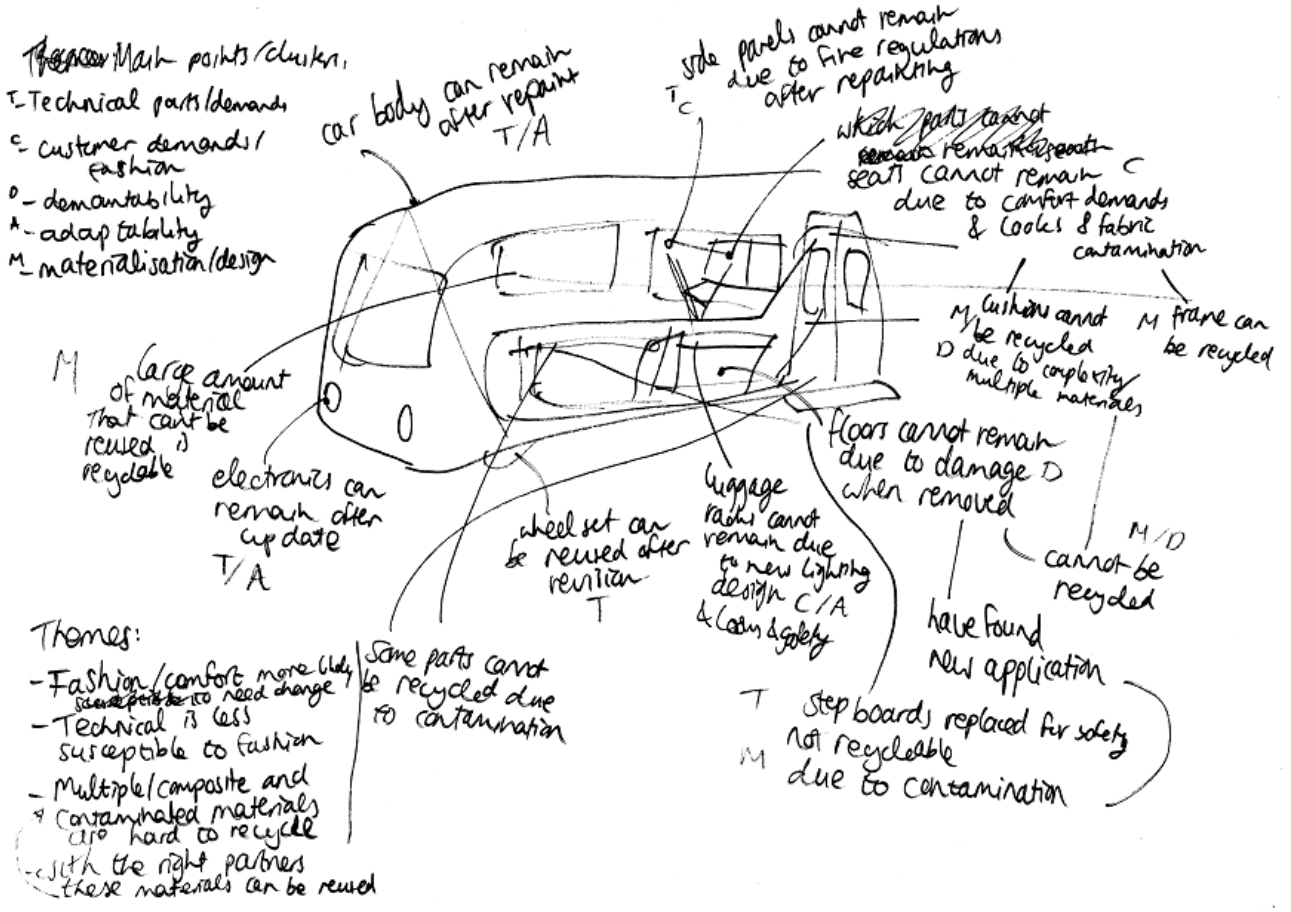


Figure 35: Overview of the annotated portfolio analysis for the VIRM modernisation

From these projects, the following themes were discovered.

| Safety: Safety is very important to NS, and it goes beyond the safety of the train itself. Upcycle solutions and reuse of parts should also have limited risks in order to be implemented. For every step or project, the consideration is made whether the sustainability benefits weigh up against risks to health, safety and public image. Think for example of the risk of chromium-6 in used train parts.

| Feasibility: An ideal solution in theory might not always be possible. It might be hindered by for example practical problems, missing links or simply the lack of interest or scale. NS is a small player in the train industry, which makes it hard to state demands. Additionally, NS is bound by tender obligations, which makes it difficult to reuse materials on a large scale within the company.

| Fashion: Parts are not only replaced due to technical lifetime duration, but also due to changing fashion demands and design vision. For example, the VIRM interior walls were still technically suitable for reuse, but as they were the wrong colour and could not be adjusted, they were discarded.

| Material selection/multi-materials: Although multi-material types have their benefits, they form a big bottleneck in the transition towards circular trains. For example, most interior walls are made of thermoset composite, which cannot be reshaped or recycled.

| Timing: Choices and change are often bound to a certain timeframe and/or deadlines. This means that sometimes quick action is needed, which compromises the quality of the solution. For example, the train requirements are set early in the tender, while it often takes another six years to develop the train. A lot of development can happen in this time, but it cannot be integrated after the deadline.

| Getting everyone on board: The sustainability department is not the only stakeholder in the train design, there are plenty of other stakeholders and their requirements to take into account. However, the train industry can be very conservative, which means that it can be difficult to realize change.

| Fit with current context: Change is always difficult, but even more so when it does not fit in the current system, as this means investments and systematic and behavioural change are involved as well. It is easier if solutions fit the current context or desires of a stakeholder group. For example, the desks made of train ceiling plates don't look any different from ordinary desks, which makes it easier to convince others to use them.

| A.2.5 Summary

NS is a frontrunner in sustainability within the mobility sector. Sustainable mobility is created through climate neutral, circular and green entrepreneurship. Circularity is more specifically defined through the WBSD definition, which describes circularity as an economic model that retains the value of circulating resources. To define the material flows over time, a train in-/outflow overview was created, which shows that most of the large train series will have to be processed in a circular manner. There are a number of themes important to consider when realizing this change: safety, feasibility, fashion, material selection, timing, getting everyone on board and fit with current context. Also, in addition to becoming circular, the train of the future will also need to be futureproof to remain valid in a changing mobility landscape.

A.3 DESIGN

| A.3.1 Design vision: closing the loop

The research in the previous section gave a number of handles to use as input for the design process. Figure 36 gives an overview of what an ideal future scenario might look like. It describes how material flows should be constructed in order to realize fully circular trains. The difference with the current scenario is that a much larger percentage of the materials is reused or recycled into new trains to keep the materials flows at a higher value level for a longer time. A sidenote here is that although reusing train material in new trains would be preferable, it could be difficult to achieve as NS has a tender obligation for contracting new trains.

To analyse how the future vision could be achieved, a roadmap was created, as shown in Figure 37. As this cycle covered mainly width and not that much in-depth analysis, this roadmap was mainly an exploration of the lay-out and contents. From this, the knowledge gaps and interesting analyses for the next phase can be determined. Additionally, it shows that it might be an interesting direction to combine road mapping with material flow mapping.

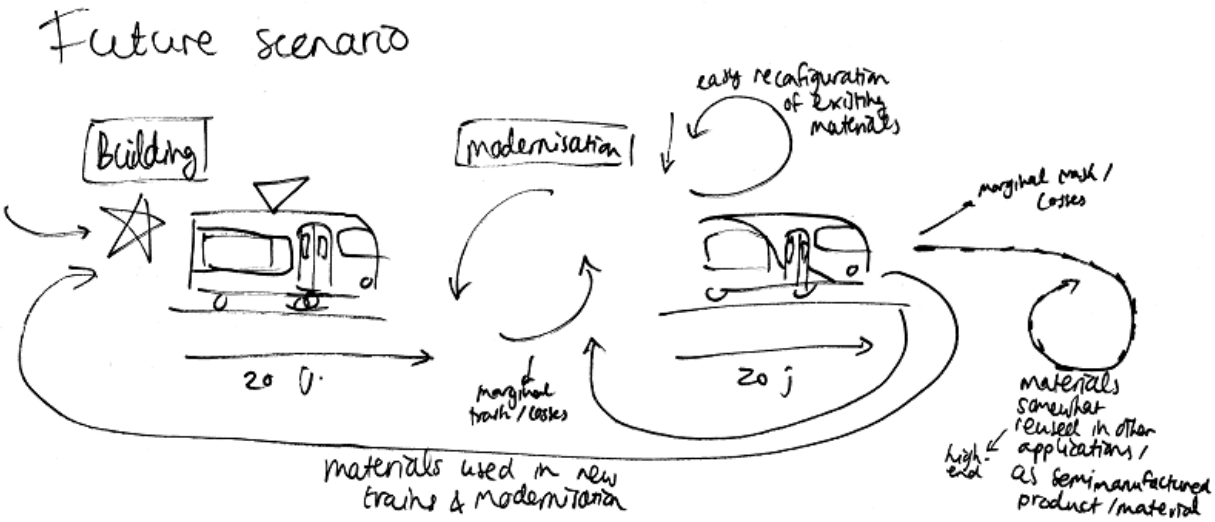


Figure 36: Future scenario for circular trains

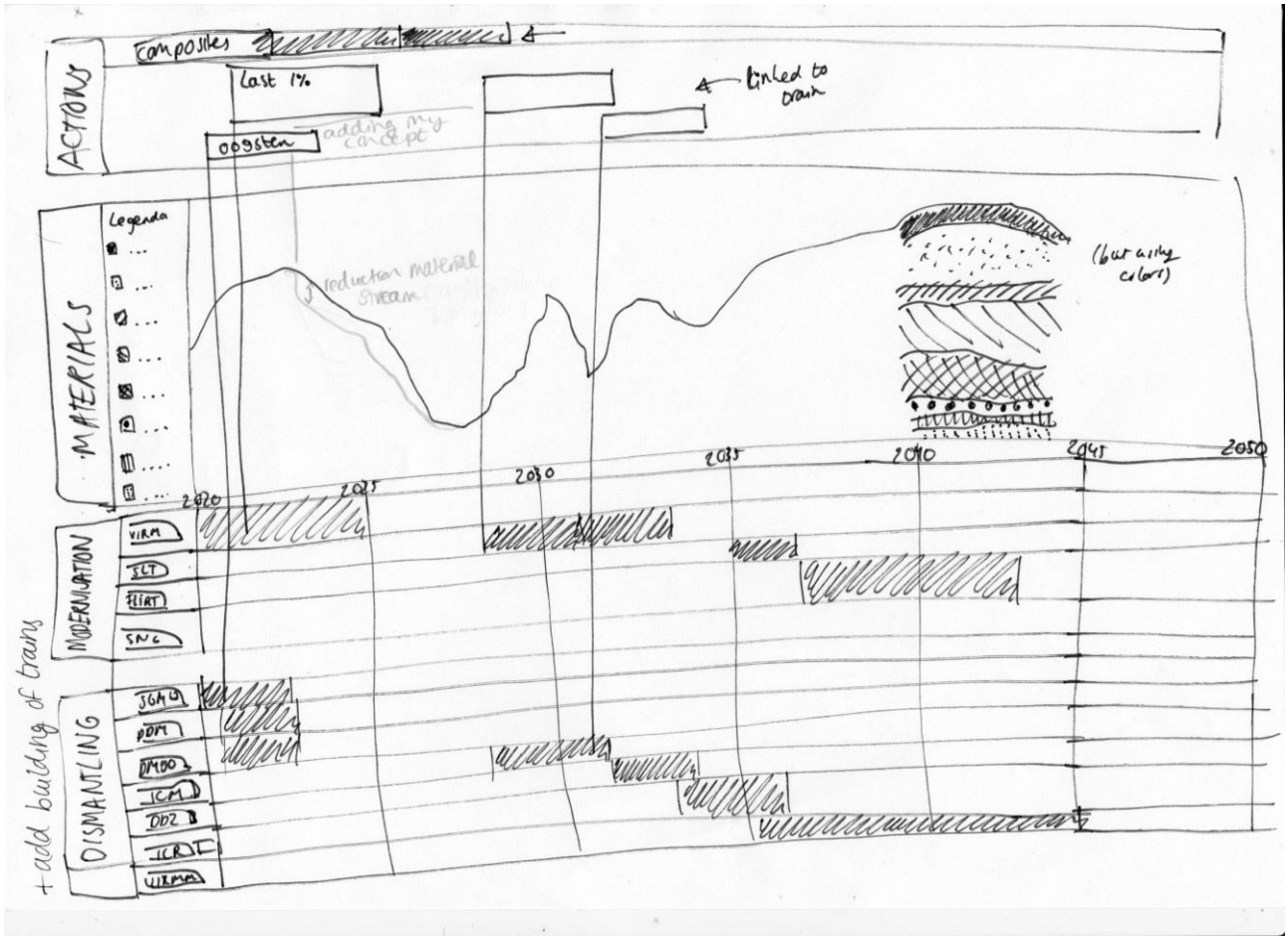


Figure 37: Roadmap/material map

| A.3.2 Concept development: repurpose used train materials

The current set-up of the roadmap mainly focuses on material flows and not that much on the actions that need to be taken for the transition towards the future vision. This makes it difficult to select a specific design problem. However, there are two main directions that can be taken when designing out waste: limit material use at the front or limit waste at the back. Both directions were briefly explored, but due to my familiarity with the latter through my internship experience, the decision was made for this cycle to design for train waste materials.

To select a relevant waste stream, the material waste streams from the modernisation of the VIRM intercity train were considered. The material waste streams from trains that cannot be recycled are the floors, side panels and luggage racks, and the foam from train seats cushions. These products are made from non-recyclable (composite) materials. Especially the side panels, luggage racks and foam seat cushions are difficult to repurpose. They have a very specific shape and are difficult to reshape. Also, the foam seats also deal with issues such as contamination from use. As most of these materials are also used in other train types, these material flows serve as a good starting point for redesigning for circular reuse.

I found inspiration in the use of mattresses as a growing medium for plants (Ryan, 2017; 2020). The foam in train seats is the same material, which means that it should also be possible for this waste stream. Additionally, it gives the opportunity to combine circular with green entrepreneurship. The concepts can be seen in Figure 38 - Figure 41. These concepts use the idea to grow plants on the train seats in multiple ways. Concept 1 uses it to create building façade elements through which green roofs and vertical farming can be created. Concept 2 applies the idea to create landscaping elements to create a playful and green park or seating area that can easily be moved around and installed. Concept 3 and 4 use the foam seats in plant boxes instead of soil. The usage context of Concept 3: Farmbox is the office-home environment, while Concept 4: Railbox envisions placing the boxes along railways to create green along the tracks that can easily be shifted in case of maintenance.

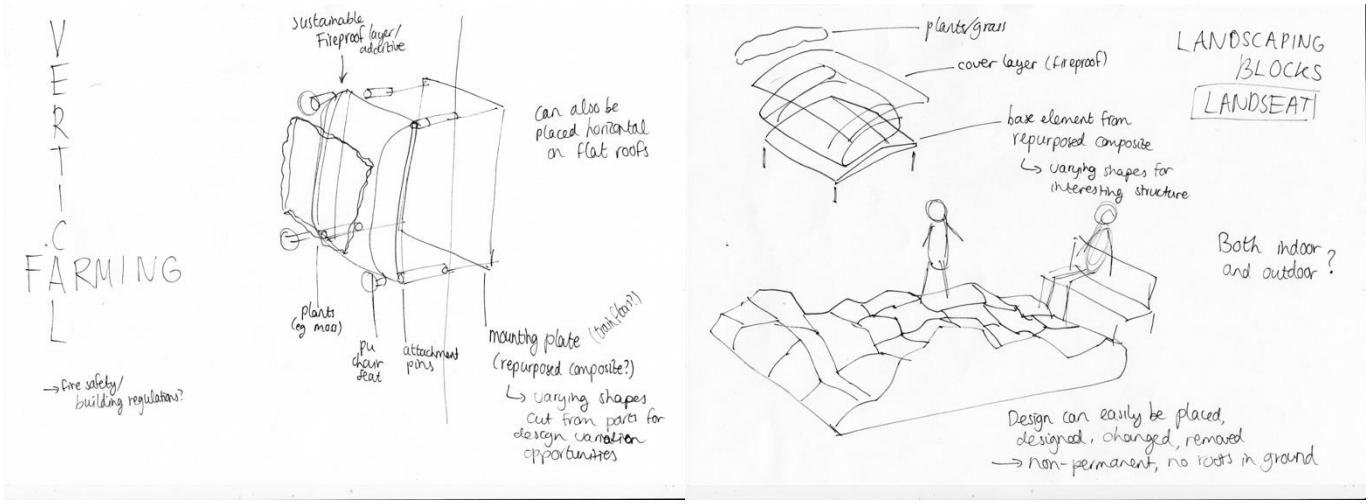


Figure 38: VerticalFarming; use the foam with plants on a building facade element

Figure 39: Landseat: use the foam with plants to create a landscaping element with varying shapes

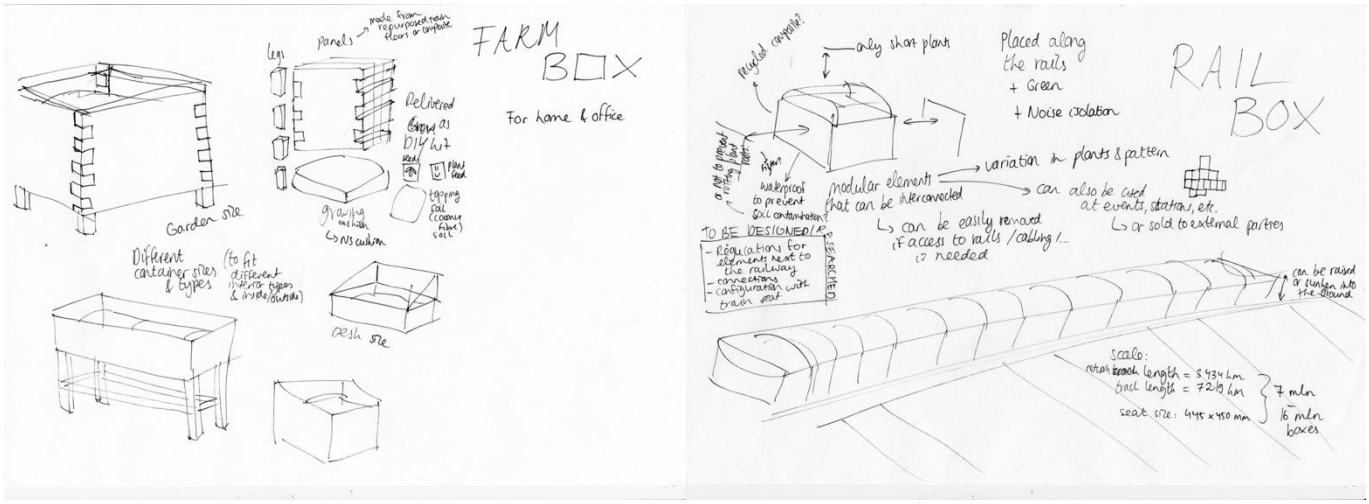


Figure 40: Farmbox: use the foam in a plant box instead of soil to grow plants at home or in the office

Figure 41: Railbox: use the foam in a plant box to create flexible green along the train tracks

| A.3.3 Concept choice

Even though these concepts would not be developed further outside this cycle, a concept selection was made, shown in Table 8. Making this selection helps to reflect on the concepts and estimate the value and potential of these concepts/concept direction, which can contribute to a better design vision. For this selection four criteria were considered, which were based on the same criteria used to judge the entries of the Spoorlab challenge. This challenge encouraged companies to send in ideas for the reuse of three train waste materials streams: train seat cushions, upholstery fabric and composite materials. As the concepts of this cycle work along the same lines, the same judgement was applied to get a quick estimate of their worth and feasibility. The criteria were:

| **Material volume:** how large a part of the available material streams can be used?
| **Feasibility:** is the application feasible or is there considerable (technical) development needed?
| **Demand:** how large is the expected demand, preferably outside NS?
| **Scalability:** how easy is it to generate a larger production/demand if the idea is successful?

Both Concept 1 and 4 show the most potential. However, Concept 1 will need quite a lot of work regarding technical feasibility, e.g. considering fire safety. Concept 4 is more feasible in technical terms, but finding the demand and approval within NS and ProRail will be quite a hassle.

Table 8: Selection best concept for cycle 1

Concept 1: VerticalFarming	--	-	+	++	Concept 2: Landseat	--	-	+	++
Material volume					Material volume				
Feasibility					Feasibility				
Demand					Demand				
Scalability					Scalability				
Concept 3: Farmbox	**--**	**-**	**+**	**++**	**Concept 4: Railbox**	**--**	**-**	**+**	**++**
Material volume					Material volume				
Feasibility					Feasibility				
Demand					Demand				
Scalability					Scalability				

A.4 SUMMARY OF FINDINGS

NS wants to be fully circular in 2030, which means making the transition towards fully circular trains.

The trend analysis of this chapter sketched the first relevant aspects of the context in which this train will operate. It shows that mobility will keep growing, but that the demands for mobility will change. More and more, a tailored and personal door-to-door journey is expected. Additionally, as technology is developed further, new competitors will arise such as the self-driving car. The train of the future will have to be more flexible in order to meet changing demands and usage patterns, as well as being able to compete with new developments. This means the train will have to incorporate customer satisfaction in addition to the technical demands of all the different NS departments.

When looking at the train in-/outflow, it can be seen that a large part of the current train fleet will have to be modernised or dismantled in a circular manner. This means that small-scale solutions for specific train materials will not be enough to make the transition, but that change should happen on a larger scale. Finding a new application for materials is often very energy intensive as this highly depends on the material type and first application. As there are a lot of material types and material variations between the same parts in different trains, there will never be a “one size fits all” solution. Therefore, only when it is not possible to reuse a material in the train, another application outside the train is developed. An opportunity here is to recognize these materials before they go in the train, and to design the parts in such a way that facilitates their second lifetime. This indicates that it would be more interesting to apply sustainable design at the front of the train lifecycle instead of the back.

Documenting the lessons learned from current projects uncovered a number of themes that will be useful to keep in mind when designing for this transition towards circular trains. These themes can

be used in two different ways: as a starting point to define a specific design problem, or as design criteria or points of attention when working on a design problem. Most of the themes affect change and circularity in a negative manner. This makes it important to consider them in any project, and to see how they can be circumvented or even be turned into strengths.

The future scenario sketched out in the design vision gives a very global impression of reconfiguring the material streams in a train. It does not give much insight into practice, but it can help to uncover points of discussion, such as whether closed or open loop practice should be applied and how this works across train series. The roadmap in the same paragraph shows the need for qualitative and quantitative data in addition to the global approach of this cycle. It serves to uncover knowledge gaps that can be worked on in the next cycle, such as more elaborate trend and material data research in order to configure the future actions for the roadmap.

The concept design of this cycle shows that it is very difficult to find a marketable application at a suitable scale for end-of-life materials. This material challenge has been worked on by many before me, such as in school assignments and the Spoorlab challenge, and the efforts needed often far outweigh the benefits. At the moment, a couple of train materials have found a repurpose destination, but realizing these few project has taken over more than a year of networking (Ilse de Vos van Eekeren, Personal communication, 2020). Far more efficient would be to shift the design focus towards the front in order to prevent this problem in the future.

A.5 CO-REFLECTION

Co-reflection with IDE coaches

During the co-reflection, it was indicated that the found sustainability definition sounds very economical, with little specification regarding impact. Circularity can be considered as a means and not as a target. For trend analysis, consider technological/sustainability trends as well, and maybe even social-cultural trends. The project in 1 day focused a lot on current practice, but how will it go in the future? For this, it is important to think of cultural changes and technological progress in for example self-driving/electrical cars. This can influence how the train of the future will be deployed. Therefore, in the next cycle I want to spend more time to see what the future context will look like and in what ways sustainable change can be realized.

When looking at train outflow, you can look to see if this can be lengthened/shortened to match the lifetime of train parts. These are design choices that can be made. In addition, the roadmap could serve to connect and integrate project aspects to make it more of a cohesive whole, instead of "ticking boxes". A possibility would be to see if the roadmap can be merged with sustainability, for example by combining it with a material map. Besides mass, the impact (e.g. CO2) and material value is interesting to consider, as well as the existing infrastructure. When designing trains, extensive consideration needs to be paid to all the different stakeholders and safety. Circular design needs to perform in the same way as the current design. Therefore, the corporate structure of NS needs to be considered, as the design needs to be executed within this structure. Annotated portfolios can serve as input for conversations, which again can serve as input for the analysis process.

For the current concepts it is doubtful what will actually happen with them after I have finished my project. However, it can serve as input for discussions. But the value in the first iteration cycle is that it helps mainly to scope and to determine what I want with my project ("visionary and inspiring") compared to the more concrete results that NS would like to see, such as the roadmap circular trains or material handbook. The project could provide deeper insights instead. The 10 cycle can provide time to better process the input in order to better facilitate stakeholder conversations.

Co-reflection with NS coach

The NS coach reflected that most of the time in this project will probably be spent doing data collection and material analysis. For this, material flows can be ordered according to the front, middle and back of the train lifecycle. The following data sets could be used to get data on the material flows: Front – SNG and ICNG/DDNG reports, Middle –VIRM1 Circular IQ report, Back – SGM harvest cards. The information is there (e.g. material managers) and data reports, but it is difficult to retrieve.

Tools for processing the data could be the CTI tool and WBCSD report indicators and definitions. In the next cycle, it will be interesting to see what data can be found.

Regarding the visualisation of the roadmap, it could show the percentage of materials that gets reused, and a "red alert button" for if and why this is not 100%. A possible concept could be (input for) a circular material handbook that indicates suitable materials for the train car body, bogies and interior, and general aspects such as connections. A possible concept could be (input for) a circular material handbook that indicates suitable materials for the train car body, bogies and interior, and general aspects such as connections.

A.6 REFLECTION

This cycle covered the whole project quite well. However, the focus was similar to that of NS at the moment: it was mainly focused on the current state and the end-of-life material streams of the train lifecycle. The idea was to take the lessons learned from the current projects and concept design back to the front and write a first list of recommendations for new train design, but this step was not reached within the time span of this first cycle. I could still look into a methodical approach on how to derive specifications from the lessons learned throughout the project. However, I think it would be even better to bring this more to the front of the project focus, and design for improving the circularity in new trains. In the next iteration cycle I want to shift my design vision and concept development to his focus, and also work on filling in the knowledge gaps that were uncovered in this cycle. I also want to work out the knowledge gaps in a more detailed manner. I want to do this by constructing a detailed material data overview for a specific train type and performing a more elaborate trend research. Additionally, I want to shift my design focus to the front of the train lifecycle and prevent non-recyclable waste materials.

Regarding methodology, I found the 1:10:100 method very useful to keep my focus on the whole project. It allowed me to try out research directions and methodology without allowing to lose too much time on it. When working on the project I also had to focus on the whole scope instead of on a single aspect. This encouraged me to consider how much a certain aspect contributed to the expected results, and whether it was worth it to spend time on it. It also forced me to move away from research and to also consider the concept design phase in the first set-up, which is beneficial as I tend to lose myself in the research phase. Therefore, I will keep this method to shape my following iterations.
I had not spent much time yet to look into Design Roadmapping, which is why the roadmap I created in this iteration looked different from the one intended by the method. It was more a material map than a visionary path towards achieving a (circular) design vision. However, Design roadmapping looks a promising method to combine both roadmapping and design. In the next iteration, I want to further look into this method to see what elements are useful and where they fit within the project.

B CYCLE '10': DEEP DIVE

This chapter presents the main findings for the project in the second iteration cycle, which had a time span of 10 days. The main goal of this cycle was to further develop the analyses of the first cycle by performing a 'deep dive' into these analyses. By spending a little more time on each step compared to the previous cycle, results of a higher quality are yielded which helps in further refining the project. Additionally, the insights and results of these analyses can be used as input for defining the design vision and creating additional design concepts. By combining this and the previous iteration cycle, the project focus is finalized, which will scope the activities for the third and final iteration cycle.

B.1 FINDING DEPTH

> *"What level of detail yields the best results?"*

Even though the project width has been established in the first iteration cycle, not all topics can be worked out in the same level of detail. Therefore, this iteration will determine what level of detail best balances efficiency and results for the chosen research activities to determine the depth of the project scope.

> *"How can 1:10:100 and Design Roadmapping help to inspire and focus research and design activities?"*

The previous iteration determined that the 1:10:100 and Design Roadmapping were both valuable methods. This iteration will go more in-depth to find out what contribution the methods can make on inspiring and focusing the project.

B.2 RESEARCH

The research in this cycle used the research directions of the previous cycle as a starting point. Firstly, the definition of sustainability was explored further through a dedicated team day and an interview with the portfolio manager of the department. Then, the trend analysis was expanded through the use of trend patterns, and a detailed train in-/outflow and material data overview was constructed and visualised.

B.2.1 Defining sustainability

To further define how sustainability is realized within the NS strategy, I attended a team day of the sustainability department on the sustainability sub-strategy. During this day, the contents and sub-elements of this strategy were discussed, as well as ownership and implementation into the main corporate strategy. This gave me more insight into the operational part of sustainability and circularity at NS. In this meeting, the difference between sustainability and sustainable entrepreneurship was clarified. Sustainable entrepreneurship is more concrete compared to the general theme. It focuses specifically on the actions that the company will undertake to contribute to sustainability instead of remaining a philosophy on how sustainable practice would ideally look like. With the new strategy, sustainable entrepreneurship becomes part of the general corporate structure, with the sustainability department acting as advisor. In 2030, NS wants to be emission free, to be on track towards 'Paris Proof' in 2050, and to deliver significant contribution to the Sustainable Development Goals (SDG's). NS will back cast from this future vision to create a roadmap and set actions towards their goal. How sustainable mobility will be achieved will change over time, but for now the focus is on innovation.

In addition to the team day, I interviewed Martien Leget, who is portfolio manager of the sustainability department. The goal of this interview was to learn more about the definitions for sustainability, the motivation for sustainability, and how sustainability fits within the general operation of NS. The definition of sustainability found in the previous iteration stated that "Sustainability is a state of a dynamic and complex system which exists in harmony without using anything outside of its system borders." However, Leget criticized that this is quite a technical description, which makes it difficult to implement within the company. The train itself is already very sustainable as it is collective transport using renewable electric energy, but there is still room for improvement regarding stations, offices and workshops. Additionally, Leget commented that NS sees sustainability as a way to distinguish itself from competition, a boundary condition for future

development, and as a social responsibility as they are a big company that stands in the public eye. Leget also mentioned in this interviewed that NS can also be very risk avoidant in their practices. This has as result that so far sustainability has mainly been implemented on aspects where it "did not hurt" as it did not influence general practice that much.

| B.2.2 Mobility trend patterns

The trend analysis in the first iteration cycle was conducted by gathering a few trends from the NS strategy report. This trend analysis was expanded by gathering numerous trends from a collection of trend reports, as found in Appendix F. These trends were clustered and laid out in the sequence listed below. I chose this approach to see the general trend development over time, thus giving an indication of the future mobility context. This resulted in the trend timeline shown in Figure 42.

| Cluster – general trend: The trend cluster describes a general phenomenon or event that influences mobility. Some trends that describe the general trend are placed in this group instead of in an underlying subgroup.
Example: Urbanisation

| 1 – Consequence: The consequence subgroup holds a number of trends that are an effect of this general trend.
Example: More traffic in the cities, travel distances become shorter

| 2 – Action: The action subgroup holds a number of trends that describe actions that are undertaken in response to the consequences.
Example: Municipalities deploy measures to create car-free city centres

| 3 – Result/vison: The result subgroup holds a number of trends that describe future developments that can be expected to result from the undertaken action.
Example: Development of new types of micro-mobility

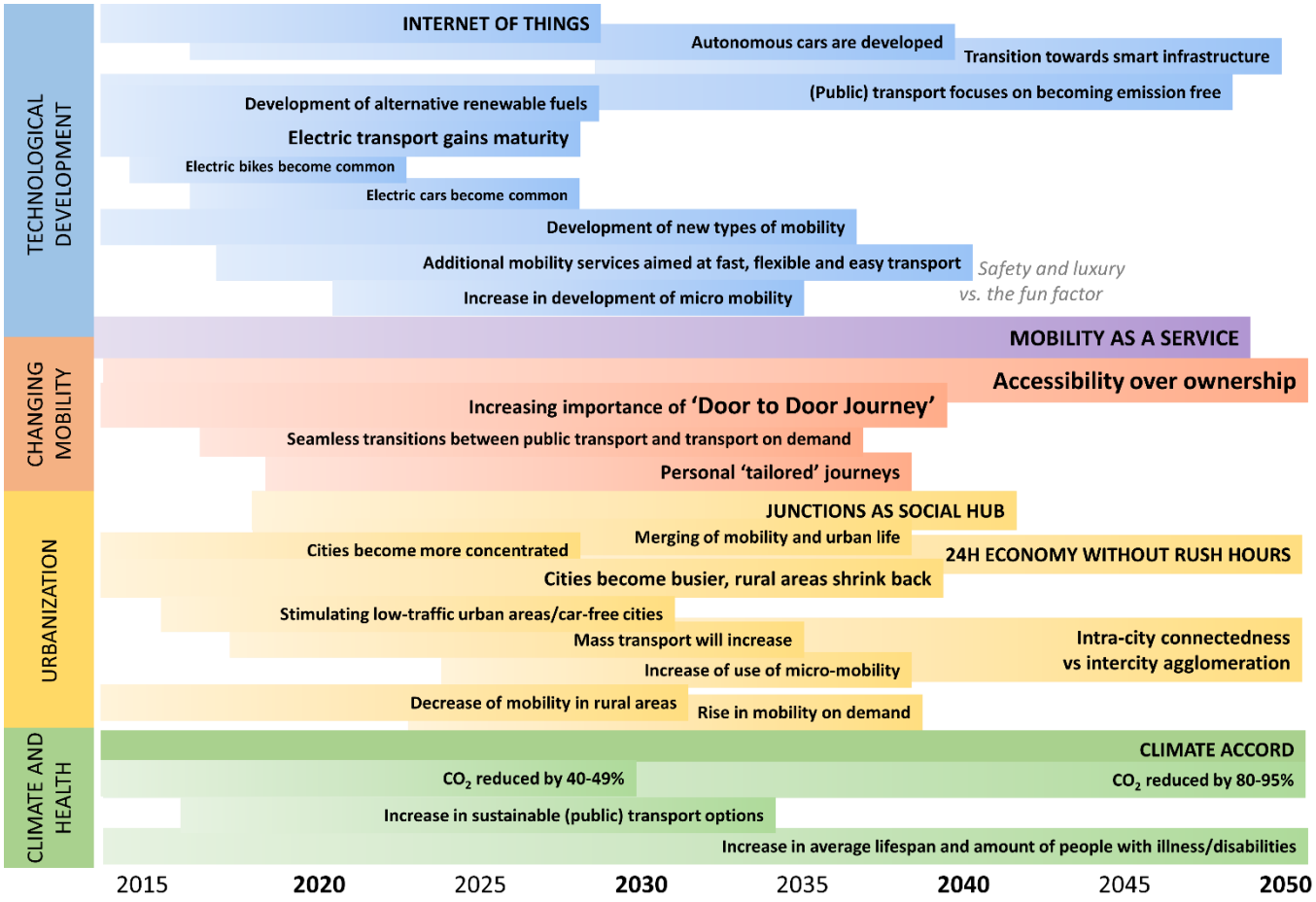


Figure 42: Trend timeline

A lot of trends are interconnected or have multiple causes and consequences, which is why there is overlap in the trends in Figure 42. The overview should not be taken as a strict timeline, but rather as an indication of how trends may develop over time and what the most important trend clusters are. The most important trends that I found, (in bold in Figure 42), are Internet of Things, maturity of electric transport, mobility as a service, accessibility over ownership, increasing importance of the Door to Door Journey, junctions as a social hub, and 24h economy without rush hours. These trends are most interesting to inspire or shape concept design.

| B.2.3 Visualising and defining train flows

In the previous cycle, a quick overview was made of the inflow and outflow of trains. However, this was not specified and confirmed yet, and lacked numbers and qualification. In this cycle, the train flow was quantified and visualised, as shown in Figure 43. Also, the modernisation phase of trains was added as well. In Figure 43 there can be seen that most train series will have to modernised and dismantled in a circular way if NS wants to be fully circular from 2030 on. At the moment, NS already achieves about 99% circularity for modernisation (86,2% within and 12,6% outside the train) and about 94-95% recyclability for end-of-life trains. However, the last few non-circular material percentages prove to be the most difficult to process sustainably, as these are mainly mixed materials with no standard circular processing method in place. This means that tailored solutions need to be found for each material type. As materials are often not well documented, often vary across train series, and are mostly difficult to process or repurpose, this will cost a lot of effort.

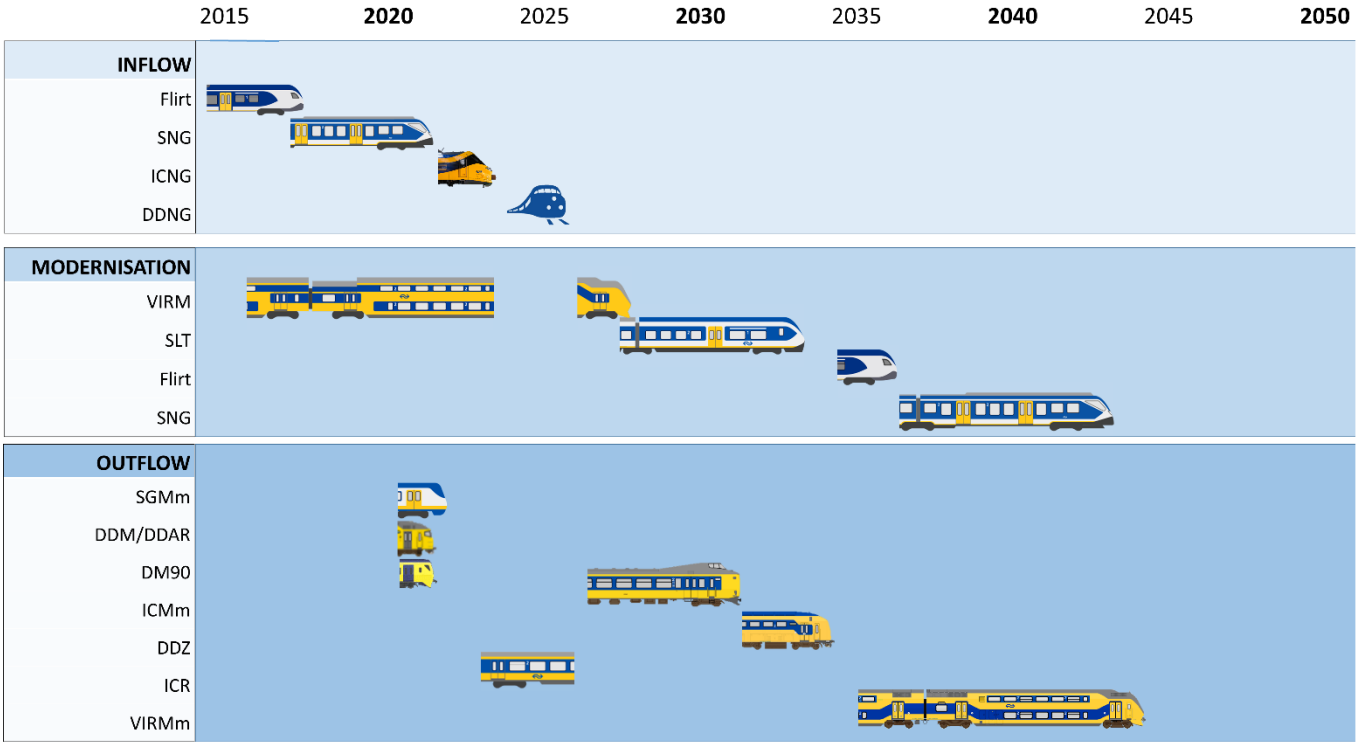


Figure 43: Train inflow, modernisation and outflow overview, data validated by Pieter van Halem, Network Organisation (NO) department NS

An additional analysis was made to document all the materials within a specific train series. This was done to find how long it would take to document a train for which there was no data overview available. For this, the SGMm train series was selected as this train already had some initial inventory on parts, weights and materials from the SGMm harvesting project. This inventory served as a starting point for the analysis. By adding weight estimates for car body, bogies and insulation – based on general average percentages – about 90% of the SGMm could be accounted for. Significant parts not yet accounted for are for example window rubbers, interior cabinets and chemicals such as primers and paints. Also, most weights are still just a rough estimate. The material analysis was made by documenting the part material and weights, and multiplying these with parts per car to get the

weight per car. Multiplying this again with the total amount of cars gave the total weight for the whole fleet. Table 9 gives a summary of the first material outflow inventory for the SGMm train. From this estimate, about 68% of the train would be recyclable and 23% non-recyclable (91% total material weight accounted for). This is significantly different compared to the average recyclability numbers, so additional validation for this analysis will be required, for example through discussion with the NS waste manager.

Table 9: Initial material outflow overview SGMm, not yet validated

Category	**Outflow material**	**Weight**	**Percentage**	**Recyclable**
Metals	Aluminium	461203	4,09 %	Yes
	RVS	6832983	60,61 %	Yes
	X5CrNi18 (304)	41580	0,37 %	Yes
	X5CrNiMo18 (316)	17325	0,15 %	Yes
Composites	Glass fibre reinforced polyester	25410	0,23 %	No
	Wood + linoleum	238650	2,12 %	No
	HPL (resin infused wood residue)	4932	0,37 %	No
Glass	Glass	249343	2,21 %	Yes
Foam	PUR foam	34015	0,30 %	No
Plastic	PET	3897	0,03 %	Yes
	ABS	3897	0,03 %	Yes
	PC	9909	0,09 %	Yes
Elastomers	Silicone rubber	1299	0,01 %	No
Fabric (synthetic)	Fabric (synthetic)	3779	0,03%	No
Wood (B-category)	Wood + paint	229996	0,20 %	Yes
Other	Electronics	1691100	15,00 %	No
	Insulation	563700	5,00 %	No
	Total	**10243019**	**90,86%**	

| B.2.4 Summary

NS sees entrepreneurship as the way to contribute to sustainability and have integrated this into their corporate strategy. The motivation for sustainability comes from competitiveness and facilitation of future growth, but also from intrinsic motivation. By gathering trends and patterning these along a timeline, a future mobility context can be sketched. Important overall trends in this picture are technological development (e.g. Internet of Things), changing mobility (e.g. Mobility As A Service), urbanization (e.g. 24h economy without rush hours), and climate and health (e.g. climate accord). The train and material overview shows that most train series will have to be processed in a circular manner to be fully circular in 2030. This is mainly a challenge for the outflow of trains, as not all materials can be recycled. A detailed material overview of the SGMm was also created, listing the material categories and types derived from the list of parts. From this estimate, about 68% of the train would be recyclable and 23% non-recyclable (91% total material weight accounted for).

B.3 DESIGN

| B.3.1 Design vision

From the research in the previous iteration cycle, I concluded that most impact could be made by focusing on the materialisation of trains at the front. This iteration explored a first design strategy vision to realize the circular train design vision created in the first iteration cycle. This design vision, depicted in Figure 44, shows a transition of design strategies and principles to transition from the current approach towards a different approach that will achieve the vision of fully circular trains. The design vision moves from the bottom of the Ladder van Lansink from recycling (design for recyclability and design for disassembly), through reuse (design for reuse and design for interchangeability, such as multipurpose elements), to reduce (design for prevention).

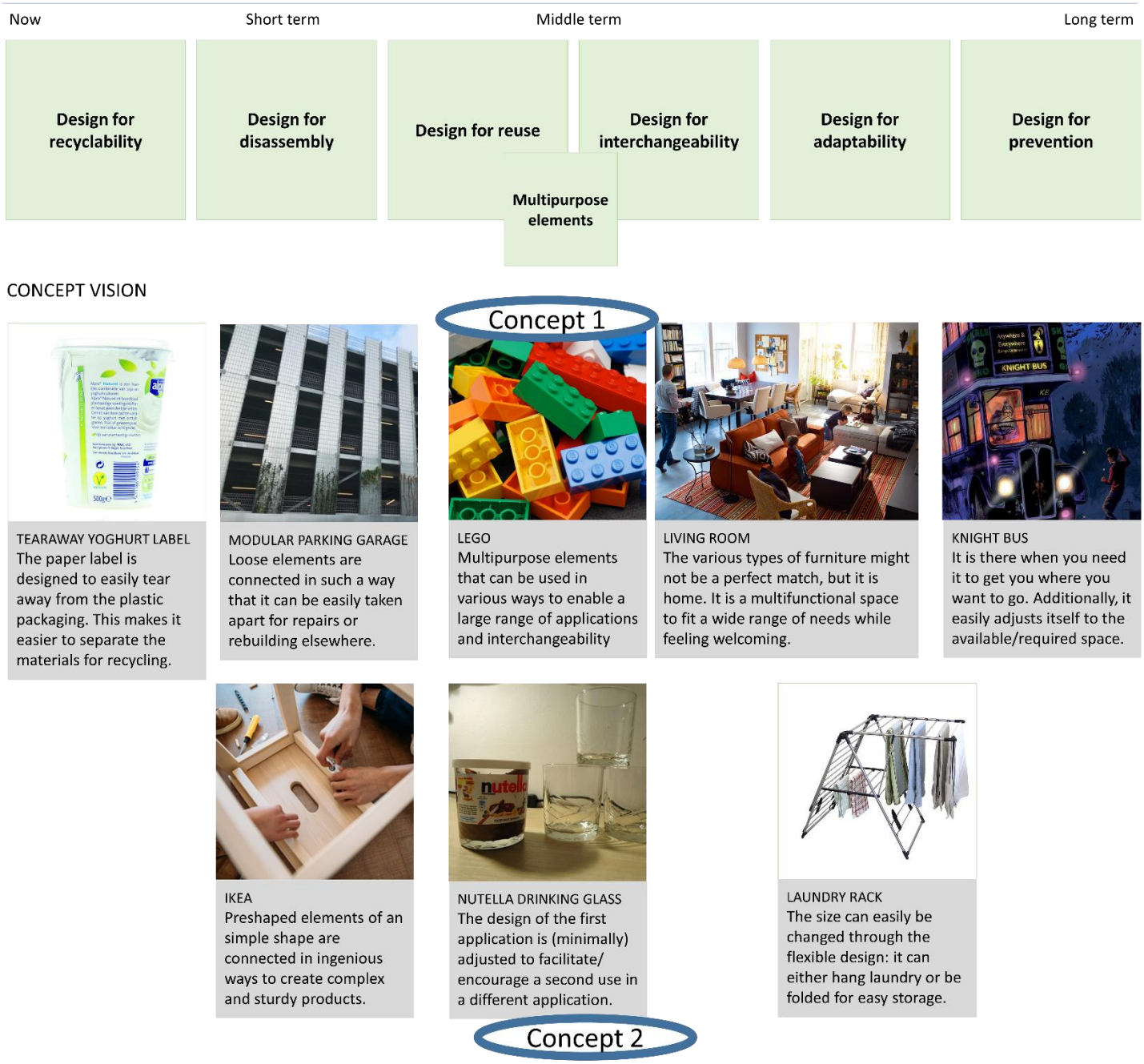


Figure 44: Design strategy vision

At the moment, NS is mainly focused on lifetime extension and the outflow of (non-recyclable) materials. Their approach is therefore mainly focused on design for longevity and recyclability, such as requesting a certain level of recyclability for their new trains. Design for disassembly is also increasingly deployed, such as the modular interior design for the train of the future. This shows that NS is shifting their focus to include the front as well. However, even though a fully recyclable train can be considered circular, the strategy shouldn't stop there. NS is a frontrunner in sustainability, and wants to stay that way. When looking at the Ladder van Lansink, recycling is only the lowest acceptable tier. Therefore, to climb the ladder, strategies that facilitate reuse of parts should be employed as well. This could be by making parts suitable for reuse in (new) trains, but also by designing parts in such a way that they can be switched around between trains, thus limiting the amount of stock needed, or to design parts to adapt to changing situations to make them more flexible and thus longer useable. Moreover, this design strategy could also contribute to better customer experience, which fits the trend research discussed before. Finally, the ultimate goal is to design for prevention. At the moment, seat occupancy in the train is on average around 30%

(Personal Communication, 2020), while it can still be very challenging to find a seat in rush hour. By even smarter planning and systematic optimization, the number of trains can eventually be limited without compromising on seating availability and customer experience.

| B.3.2 Concept development: circular train interior

To give shape to the design strategy, two concepts were designed. These two concepts both explored the Design for reuse/interchangeability principle, although in two different directions.

Concept 1, presented in Figure 45, explored the direction of A multipurpose element would reduce the amount of different parts in a train. It envisions creating two standard building elements, rigid and soft, to build the whole train interior from. This standardization of parts means that a lot of parts can be interchanged; a part that might not have sufficient strength any more as wall or floor element, could still serve as a seating element or luggage rack for example. Additionally, it would mean that less stock of spare parts is needed in order to be able to maintain and service the trains.

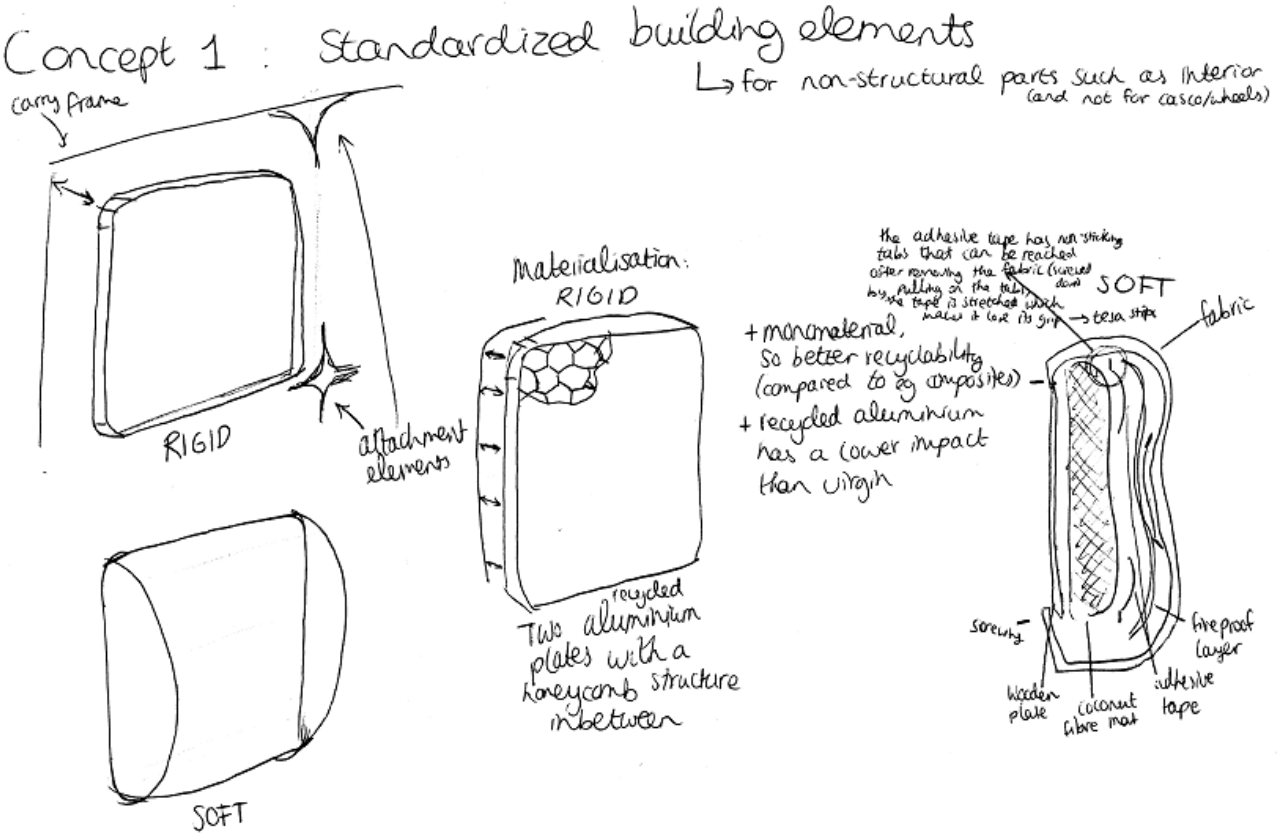


Figure 45: Standardized building elements: a rigid and soft element from which the whole train interior can be constructed

Hard surfaces such as walls and floors can be made by interlinking the elements to carry frame. To change appearance and enable easier cleaning, an adhesive top can be added, such as a linoleum or rubber layer on the floor. Benches/chairs chain be made by combining the rigid elements with soft elements. If needed, plates can be made thicker by stacking them. To create a strong yet lightweight structure, the rigid elements can be made from aluminium plates with a honeycomb core. This creates a mono-material part which is easier to recycle than for example a fibre reinforced composite material. Ideally, the elements would use recycled aluminium, as this has much lower environmental impact. For the soft elements, a sustainable foam core such as coconut fibre foam can be used on a wooden backing plate. The fireproofing layer in-between is often the tricky part in the dismantling. So instead, a reversible adhesive solution should be used. An inspiration for this could be the Tesa powerstrip: these adhesive stickers are very stretchy, and by pulling on the non-sticky tabs, the tape is stretched in such a length that it loses its grip on the sticking surface. Research would be needed to see whether this technique would also be applicable in this application.

Concept 2, presented in Figure 46, explored the direction of designing for a second lifecycle as a desk chair. In this concept, the train chair is redesigned to be able to transition to a desk chair after use in the train without too much modifications. Additionally, as there are circular desk chairs, this can serve as inspiration to create a circular and recyclable train chair.

The chair would be created by putting the desk chair design in an overall cover frame to give it the additional strength and stiffness needed for use in the train. After use, the chair can be transitioned by removing this cover and switching the underframe. The problem with used train seats is often the contamination of the fabric and foam. This can be countered by using a fabric that is easier to clean and/or the use of a non-permeating layer to prevent the leeching of contaminations. A zipper on the cushion, hidden by the overall shell, could make the cover easier to replace. Also, the lifetime of this fabric cover could be extended by using a two-sided fabric material and allowing the fabric cover to be turned inside-out to hide for example colour fading. The back of the chair can be designed in such a way that it has no back pillow, as is the case in some desk chair designs. By creating an ergonomic curve in the back of the chair, the chair will make both a comfortable trains seat and desk chair. Additionally, the perceived comfort of the chair can be influenced by optimizing the shape of the cover frame: especially during short usage periods, the perceived comfort is strongly influenced by the appearance of the chair (Erol, Diels, Johnson, Richards, & Shippen, 2014). Another possibility could be to add cushioning, and remove this when transitioning towards a desk chair. As the desk chair uses the bare back plate, no additional measures need to be taken regarding contamination.

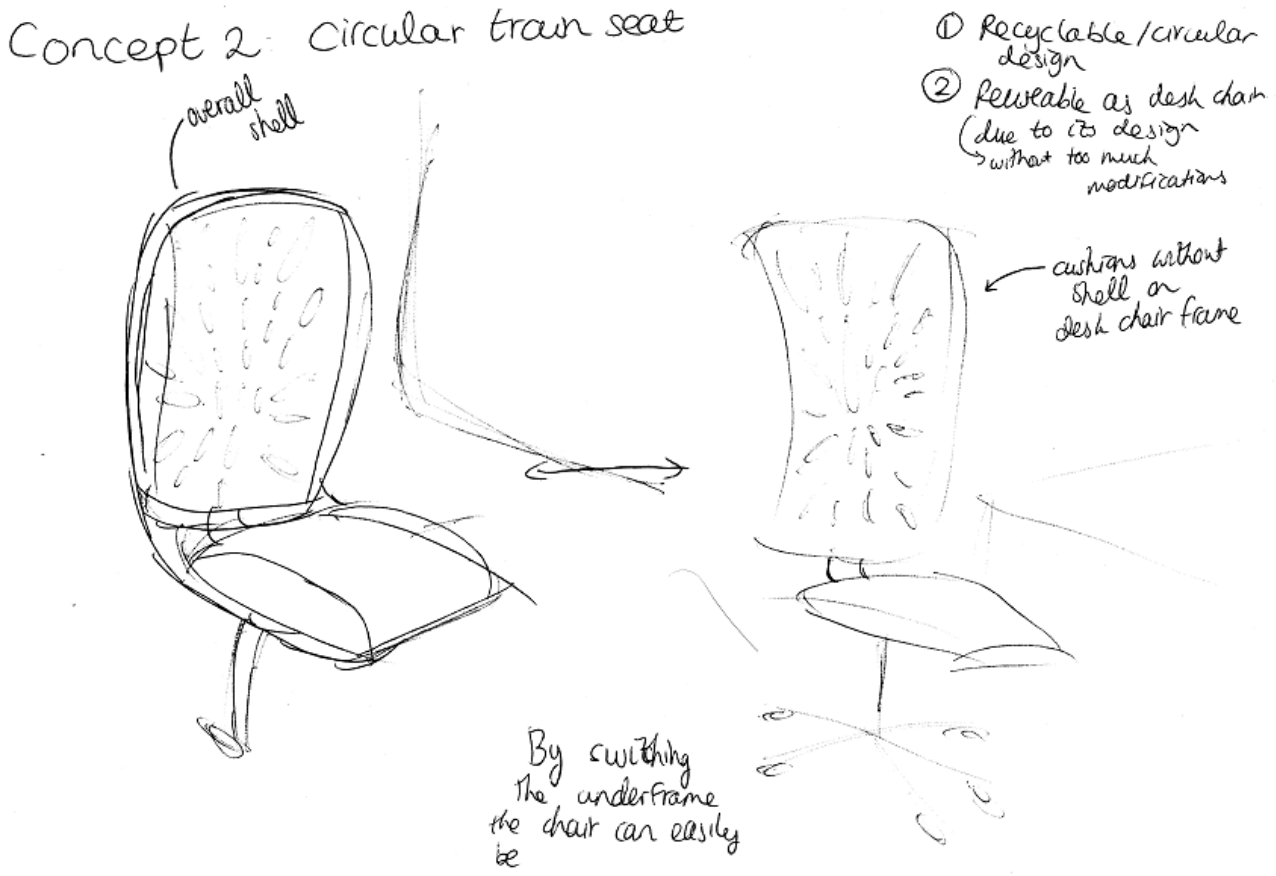


Figure 46: Circular train seat: a train seat that can be transformed to desk chair with minimal adjustments

B.4 SUMMARY OF FINDINGS

NS focuses not on just sustainability, but on sustainable entrepreneurship. Sustainability is seen as a way to distinguish itself from competition such as more polluting means of transport, a boundary condition for future development, and as a social responsibility as they are a big company that stands in the public eye. In the future, the context in which the train operates will change, such as a 24h economy without rush hour, or the rise of competitors such as the autonomous self-driving car. NS

can be very risk avoidant in their practices, and so far sustainability has mainly been implemented on aspects where it did not influence general practice that much. Moreover, it does not help that the train recyclability is already very high, which makes it difficult to express the need for circular change or the impact that a certain change or improvement would make. To still realize the transition towards circular design, two approaches can be taken: the first is to convince the company board of the need and benefits for sustainable change. The other way would be to design in such a way that it can be implemented seamlessly while still making a big sustainability impact. These approaches could also be combined or treated as short-term and long-term options. The concepts of this iteration cycle explored what preventing non-recyclable material flows through design could look like. The ideas made use of the notion to limit material use and redesign for a second lifecycle. This generates far more structural impact than designing for the reuse of end-of-life materials.

B.5 CO-REFLECTION

Co-reflection with IDE coaches

The overview is mainly focused on materials, and lacks insight into the interconnection of parts and materials. For example, interior parts often have a lot of mixed materials. For the design vision, the distinction can be made between product function and technological design approach. Reuse and remanufacture for example are product strategies, whereas disassembly and adaptability are technological design principles that facilitate these strategies. Also, prevention is different as it operates on a product-service level. It helps to look at the big picture, and see what the roadblocks are; circularity is a means and not a target. It can be inspirational to see what other countries are doing in terms of sustainable mobility. Additional iterations of the content and visuals can help to make them more convincing. The '100' cycle will give you more time for these iterations compared to the quick and dirty work of the 1 and 10 cycles. Communicate with NS what their feedback is; for this strong visuals and examples such as with the design vision are helpful.

Co-reflection with NS coach

The trend research should also be aimed at trains, recyclability & NS. What does it mean? For the design vision, NS is currently working with design for recycling, disassembly and longevity. A trend is currently to look at accessibility over ownership. E.g. we don't want printers, we want to print. This needs to be translated to the conservative train industry. The vision for the train of the future is to order an "empty box with modular building blocks". This will call for standardization of parts, reducing the amount of parts, and implementing modularity.

B.6 REFLECTION

In the next iteration, I want to validate the research I have done in this cycle through discussion with the relevant NS departments and additional research. Also, I want to tailor my trend research more towards sustainability, and rework my design vision. My design vision is currently a collection of relevant principles and methods, but the cohesive story over time and the connection to the train is missing. To work this out further I want to combine the future vision of the Roadmapping method and the application of design principles to specific sections of the train. As I mainly aimed my deep dive at the research part of my project, I did not have much time for concept development. In my next cycle I want to spend more time on the development of concepts. I found that this concept direction worked better in terms of generating impact, but that the design ideas were still quite complex. This does not fit with the conclusion that change should either be convincing or fit within the current usage contexts. In the next cycle, I want to narrow down towards a simpler design, to create something that will be actually feasible to implement. By combining this design with the future roadmap, both long term vision and short term feasibility will be covered, which optimizes the generated impact. The concept will be a practical solution for implementation on short term, whereas the future roadmap will remain more theoretical and describe all future steps towards circular trains.

C CYCLE '100': LONG RUN

This chapter presents the main findings for the project in the third and final iteration, which had a timespan of roughly 55 days. The main goal of this cycle was to make the long run, and move along the width and depth of the project scope. This way, a final design vision and concept design can be constructed to make a contribution towards fully circular trains.

C.1 QUESTION:

> | *"How can NS achieve circular inflow and outflow during building, modernisation and end-of-life for the train interior, car body and bogies?"*

The previous two cycles have provided varied amount of data, insights, input, and methodology to use as a working base to come to a final result. Part of this result is a future design vision and concept design illustrating how NS can make the transition towards fully circular trains.

C.2 RESEARCH

The research in this cycle used the research directions of the previous cycle as a starting point. Firstly, the trend research was expanded by researching the future trends in consumer behaviour and sustainability, and secondly, the material flow analysis was expanded by including the material flows of two other train series. In addition to this, two other analyses derived from the Design Roadmapping method were added: the train breakdown and the historical timeline. The train breakdown was used to show more interconnectedness within the train structure as opposed to a just a flat material list, and the historical timeline served as a tool to check the pacing of the future vision and as a tool to judge how viable developed concepts would be.

| C.2.1 Interconnection consumer design and sustainability trends

A large amount of trends were gathered again on the topic of design, corporate strategy, consumer behaviour and sustainability, using various trend reports as found in Appendix F. These trends were then clustered and laid out in a web pattern, as shown in Figure 47.

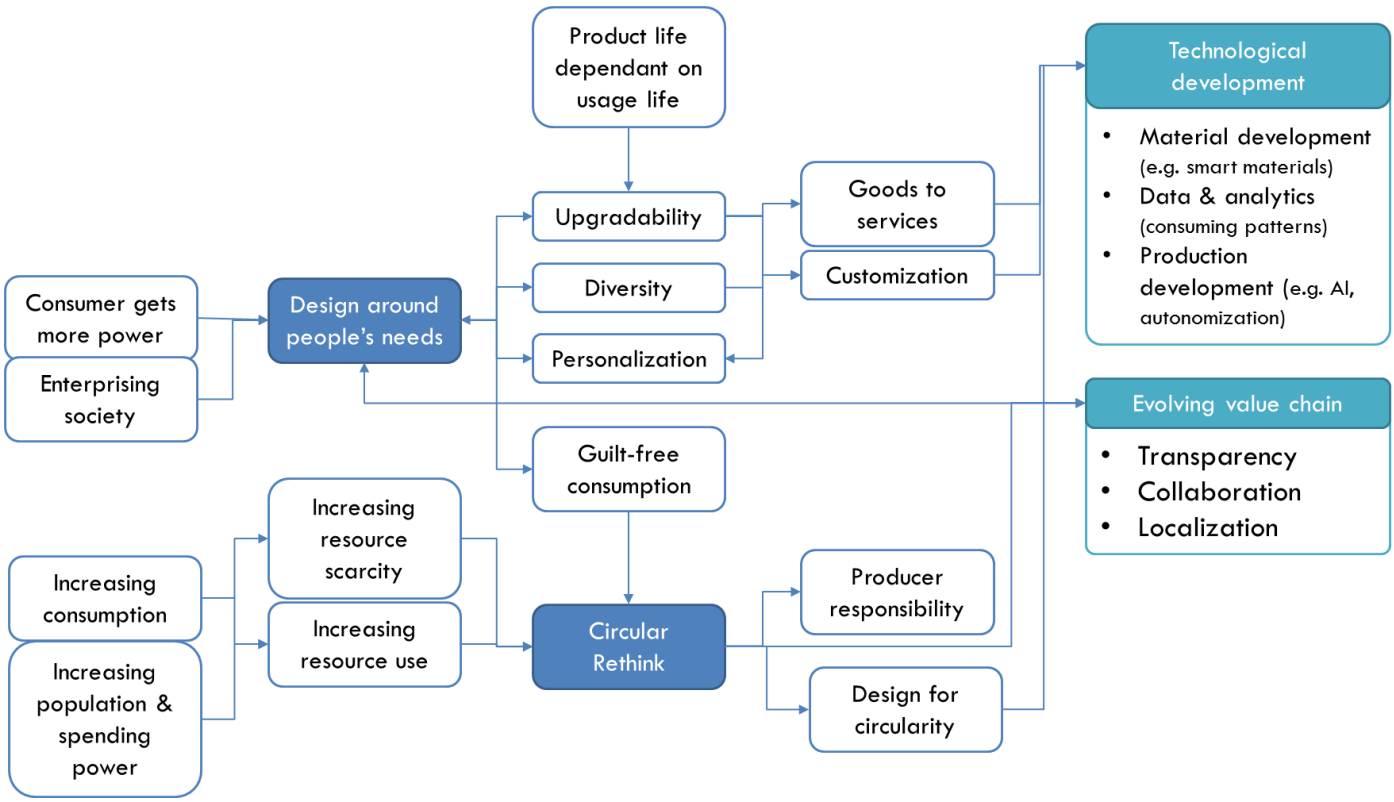


Figure 47: Design strategy and sustainability trend pattern web

The pattern web shows the interconnections between trends, which contribute to the two main themes in Design and Sustainability, which are "Design around people's needs" and "Circular Rethink". Most trends found within this trend analysis can be referred as a contributor or consequence of these trends. On the right, two additional themes are indicated, which act as boundary conditions for the execution of the two main themes.

The most interesting insight from this figure is that there is hardly any connection between Designing around people's needs and Circular Rethink. This could explain why design for sustainable change is mainly driven by NS, instead of originating from the industry and/or consumer requests.

| C.2.2 Material flows

The previous iteration near-completed a material analysis of the SGMm sprinter train. Although this was insightful, it took a lot of time to construct, even with a rough indication of materials and weights as starting point. It was therefore not feasible to perform similar analyses for other train series. Therefore, the flow analysis was expanded by processing the material data reports for the VIRM double decker intercity train and the SLT sprinter train. These train series were selected purely on the basis that this was the only available information. A more complete picture of the material flow between now and 2030 would have been achieved by adding the ICMm and ICRm trains, as these are relative large train series with low sales potential. The material analysis for the VIRM made use of internal Circular IQ material reports (commissioned by NS) for the VIRM1 and VIRMm1, and a reuse/recycle/dispose overview for the VIRM modernisation. These datasets were 100% complete. The material analysis for the SLT made use of a data overview provided by Bombardier, the manufacturer of the train. This gave about 57% of the total weight, but it missed the weight of the bogies. The weight of the bogies was averaged on 35% for the SGM sprinter, so using the same weight percentage, a material flow of about 90-95% accuracy could be constructed for the SLT.

The final material flow, shown in Figure 48, is constructed by combining material flows with the number of trains found in the train flow analysis. In this figure, the recyclable material weights are shown as positive, and the non-recyclable material flows as negative. Not all material types were available for all train types; for example, no elastomers were reported for VIRM, even though there is rubber around the windows. Still, Figure 48 gives a good first estimate of the material flows between 2020-2030.

Figure 48 shows that even though the SLT is not corrected yet for material reuse during modernisation, the amount of non-recyclable material is almost negligible compared to the recyclable material flow. This is mainly due to the high weight percentage of metals due to the heavy car body and bogies, and the low weight of non-recyclable materials such as glass fibre composites. To put it into perspective, VIRM is 79% metals, SLT around 82%, and SGM an estimated 65%. The weight percentages of composites in the train however are between 4-7%, while this material makes up the largest share of the non-recyclable material stream. An important side note here is that weight percentages can be misleading. Weight does not say anything about the absolute sustainable impact of these fractions, such as for critical materials in electronics for example. Therefore, it is important to look beyond weight when selecting focus for impactful sustainable change.

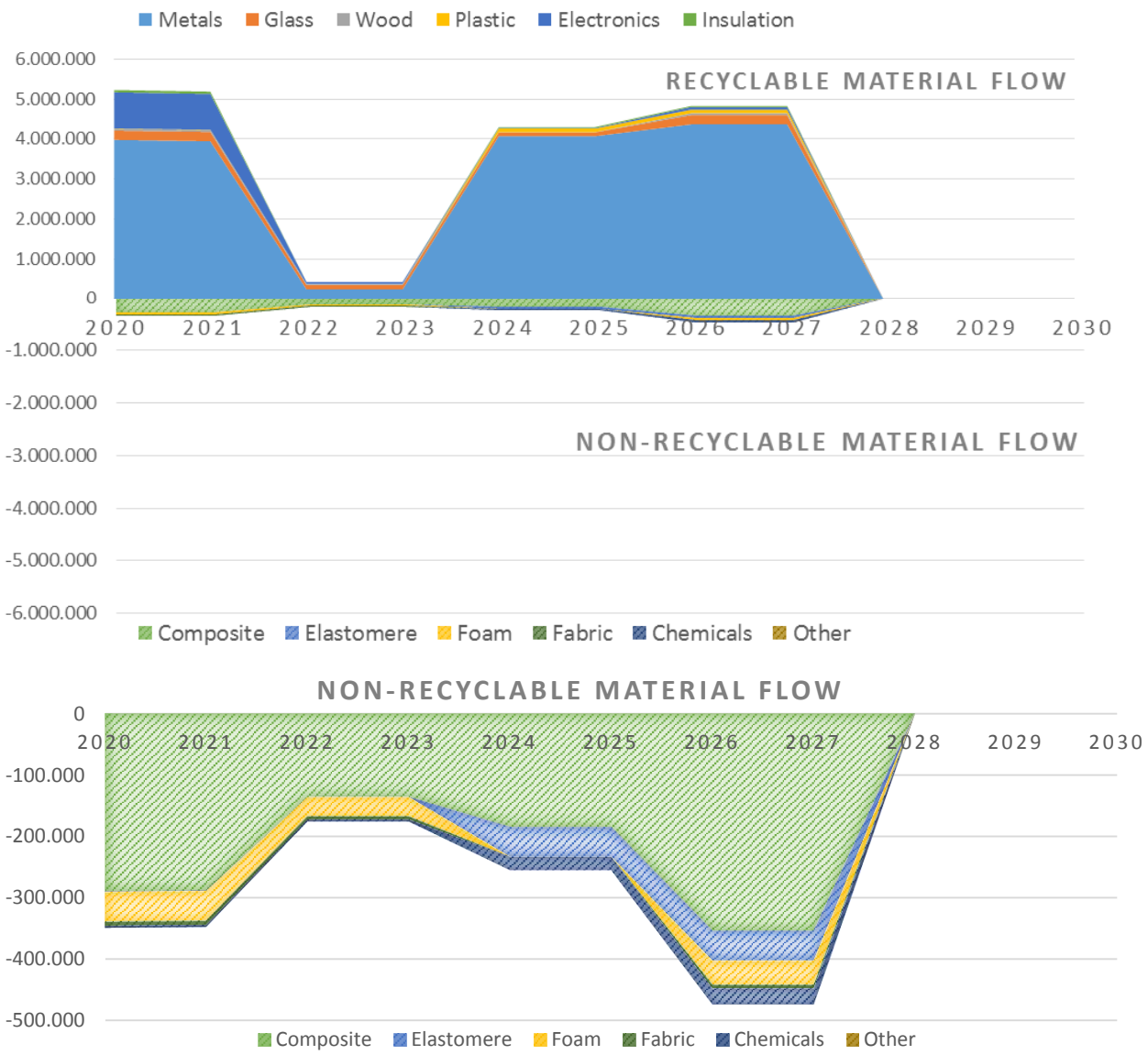


Figure 48: Overall and non-recyclable material outflow 2020-2030 for SGM outflow, VIRM modernisation (corrected for material reuse in modernised train) and SLT modernisation (not corrected for material reuse in modernised train)

| C.2.3 Train breakdown

The material flow created in the previous paragraph is very useful to get more insight into the different material types that are used in the train, their weight percentages, the ratio recyclable to non-recyclable, and how this all develops over time. However, it doesn't give any insight into how a train is built up. It is difficult to say how circularity can be achieved for a material stream, as different part/categories have very different demands. Therefore, a system breakdown of the train was constructed along the lines of the Design Roadmapping method.

First, a structural breakdown was made and the parts were sorted into subgroups in order to see how a train is built up. This allows to go more into depth on how circularity can be achieved, while still being applicable across multiple train series. The structural breakdown of a train car, shown in Figure 49, distinguishes four main subgroups: car body, systems, interior and bogies. All subgroups have their own colour. A train carriage is constructed by first building the carbody. Then, all the necessary systems are installed, followed by the placing of the interior. Finally, the complete upper section of the train is mounted onto the wheel sets.

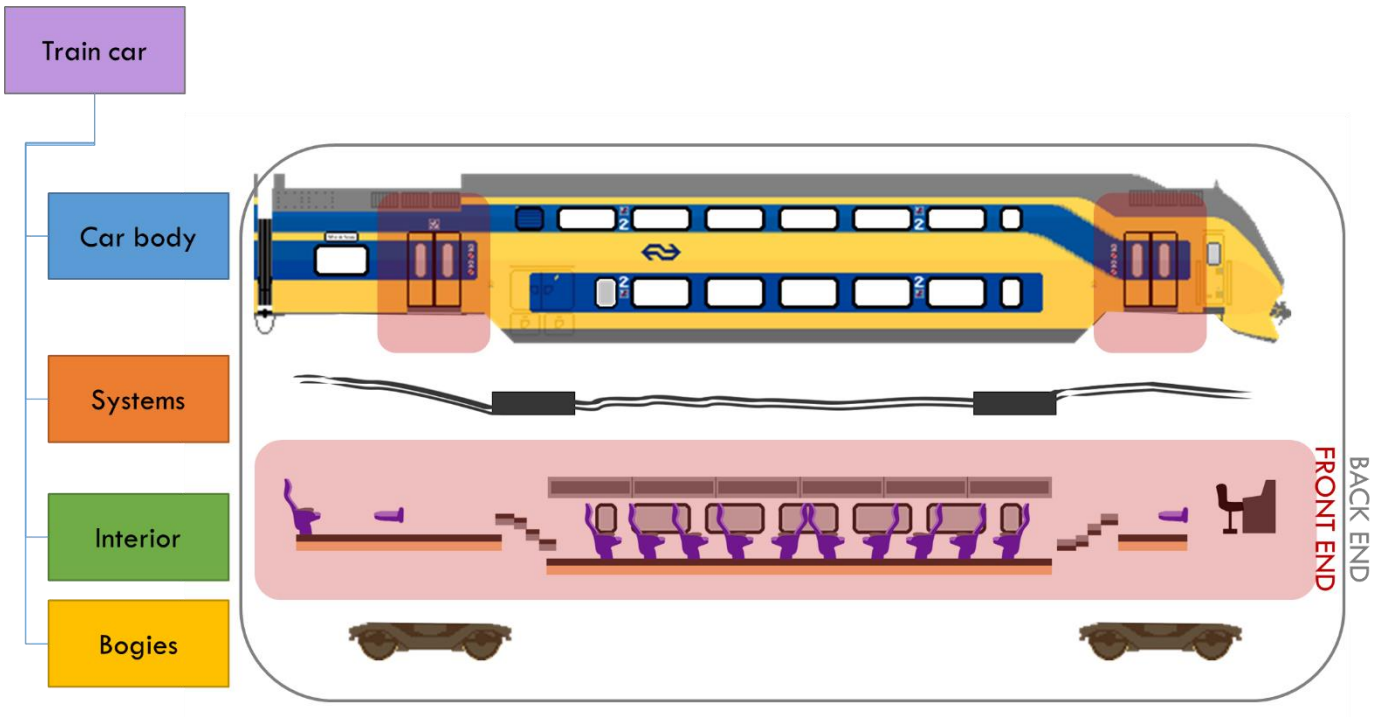


Figure 49: General train system breakdown; base image retrieved from Arthur's Treinenpagina (Pijpers)

After the structural breakdown, the parts were clustered. While clustering, all parts are coloured in correspondence to their subgroup. The clustering was done on two main themes: part criticality and part accessibility. Part criticality is derived from prevention, and is used to analyse what the importance is of the train parts and if there are any redundant parts. Part accessibility serves to see how easy it is to reach train parts, for example for repair or adjustment.
Part criticality was set out along two axes, which were criticality for technical operation and criticality for customer satisfaction. This gave four clusters: Comfort (parts mainly important for customer satisfaction), Functional (parts mainly important for technical operation), Critical (parts important for both) and Redundant (parts important for neither). Part accessibility was set out along the same way, with the axes being removal effort and part depth. This gave the clusters Anchored (superficial but difficult to remove), Permissive (superficial and easy to remove), Buried (hidden beneath other parts but easy to remove) and Anchored (hidden beneath other parts and difficult to remove).

Sorting the parts in the clustered was done using the insights I gained during my internship at the SGMm harvesting project. Within this project, the dismantling of parts has been discussed numerous times to find out which parts were suitable for harvesting. Also, the price for the parts was also determined based on how long it took to dismantle a part. This knowledge gave me a good starting point. The analysis was further validated through discussion with Ronald Terlouw, production engineer at Engineering NSTM. From this validation, an important sidenote to add for this analysis is that the assembly of trains varies widely. For example, the SGMm sprinter train is trickier to dismantle than the VIRM. The latter is assembled in layers, and after one layer has been "peeled off", the next layer is easily accessible. For the modernisation, dismantling flow schemes have been constructed to aid this process. Still, if a part in a lower layer breaks for example and needs to be replaced, it still should be kept in mind where it is located. Another consideration is that the parts have been somewhat simplified in this overview. When considering the toilet, the toilet bowl itself is easily enough to access, but the water tanks for the toilet are buried much deeper. These two sets of four clusters were then combined into sixteen meta-clusters, as shown in Figure 51, of which nine clusters were populated. These are the clusters Shape, Operate, Engage, Enable, Convenient, Experience, Support, Backbone and Accommodate. The naming of these meta-clusters is based on how they are encountered/experienced by travellers. This proved to be quite hard, as it is difficult to cover the whole implication of the cluster in one word. However, the clusters quite effectively group together parts that can be approached in a similar manner.

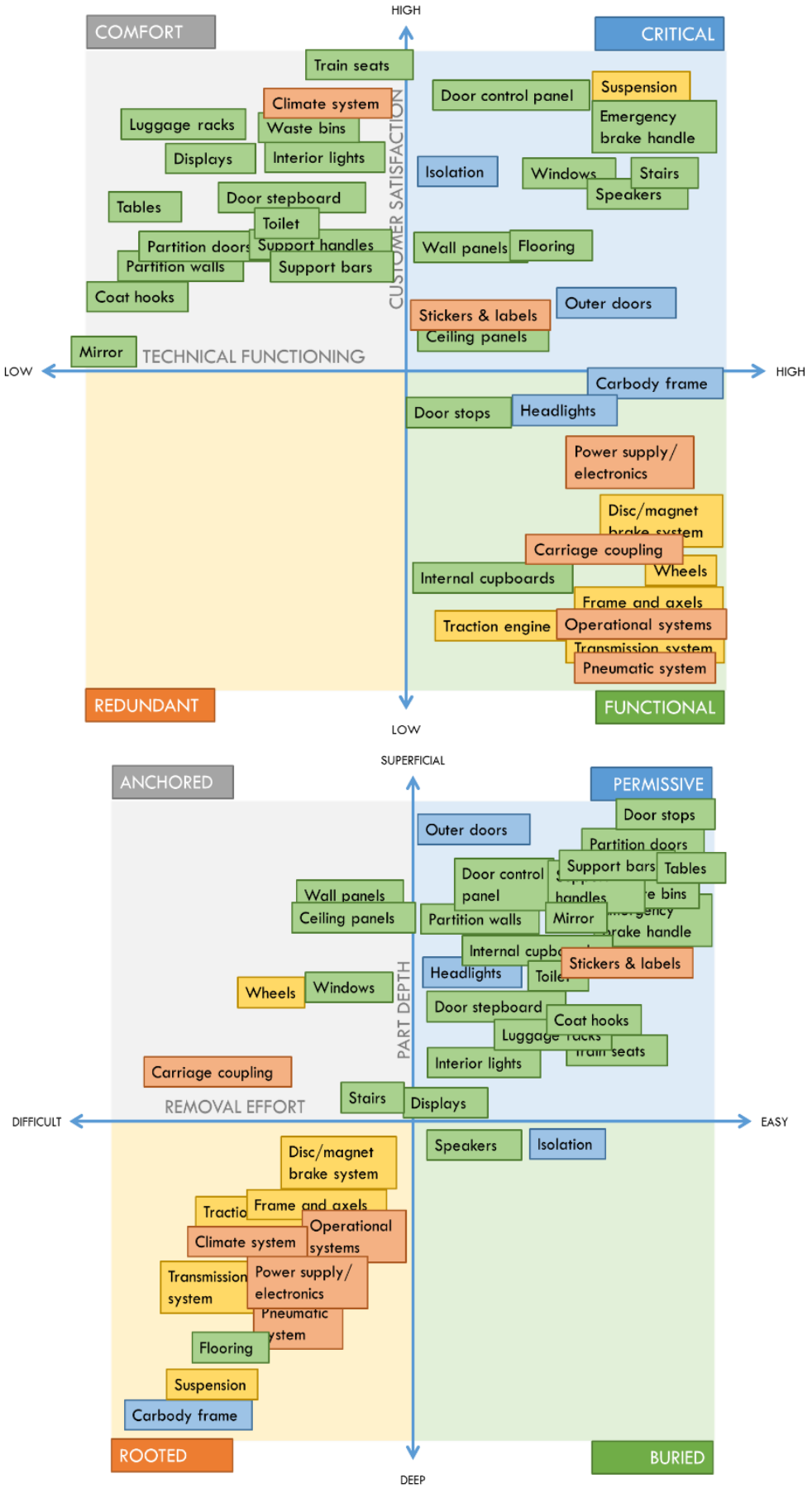


Figure 50: Clustering of train parts, validated with Ronald Terlouw, Engineering NSTM

	COMFORT	CRITICAL	FUNCTIONAL	REDUNDANT
ANCHORED		**SHAPE**	**OPERATE**	
		Windows Wall panels Ceiling panels Stairs *(optional)* Flooring	Wheels Carriage coupling	
PERMISSIVE	**ENGAGE**	**ENABLE**	**CONVENIENT**	
	Door stepboard Partition walls Partition doors Interior lights Displays Luggage racks Coat hooks Support handles Support bars Tables Toilet Mirror Train seats Waste bins	Outer doors Emergency brake handle Door control panel Stickers & labels	Headlights Internal cupboards Door stops	
ROOTED	**EXPERIENCE**	**SUPPORT**	**BACKBONE**	
	Climate system	Suspension	Carbody frame Traction engine Frame and axels Disc/magnet brake system Transmission system Operational systems Pneumatic system Power supply/electronics	
BURIED		**ACCOMMODATE**		
		Speakers Isolation		

Figure 51: Meta-clusters of train parts

| C.2.4 Timeline/design pacing

To validate my design vision, a historical timeline of NS as a company was constructed using the history on the NS website and the NS year reports. For the first part of the timeline, the available information was limited. Later on, the displayed events mainly focused on company development, company strategy, and implementation of innovation and design. Through this analysis, the general company and design pacing can be determined as it shows how fast the company develops and how often new innovations or decisions are implemented. From the timeline, displayed on the next pages, there can be concluded that NS has updated their strategy multiple times, but that they mainly work along the same lines with the customer as main focus point. It also shows that they have experimented with innovations in the past, such as Wi-Fi and electric OV bikes, and that these are implemented fairly quickly. An important event in the timeline is 2015, where public confidence in NS decreased due to the Fyra debacle and concession errors in Limburg. Around the same time, NS staff also criticized the state of the train and tracks (van Gompel, 2015). I believe that these events, togehter with the Chromium-VI case in Tilburg, have led NS to become a more careful risk-avoiding company.

The historical timeline on the next pages also shows that train interior has changed very little over time. Change is mostly very subtle and focused on materialisation, such as the lighter/thinner chairs, use of composites. And even then, change is quite slow. According to Biron (2003), composites have been used in trains since around 1960. However, the first NS train to use composites stems from 1994. This is a 30-40 year difference, in which at least four new train series were built.

1804 - Pen-y-darren steam engine (not in NS service)

1839 - Arend steam engine + 1st, 2nd & 3rd class carriage

1865 - Steam engine SS 13

1874 - carriage SS C 218

1908 - ZHESM electric train BC6 + 2nd & 3rd class interior

1934 - Mat '34 diesel train + 2nd & 3rd class interior

1946 - Mat '46 diesel train + 2nd & 3rd class interior

1804
First 'train': steam engine on wheels.

1837
Hollandsche IJzeren Spoorweg Maatschappij (HIJSM) is founded.

1860
325 km of train track is completed.
Staatsspoorwegen (SS) is founded to further the construction of a State railway network.

1900
Railway network approaches its current size.
Many new train and tram companies are established.

Between 1918-1940
Combustion engines gain traction, and bus becomes a strong competitor.
Introduction of new train types, e.g. diesel train.
NS acts as quality inspector for train building.

1940-1945
WW2
Regular work is carried out for as far as possible.

1945
Through the war, 60% of the track is unusable, and 220 train bridges have been demolished.

1800 — 1900 — 1950

1824
First railway line in England.

1839
First railway line in the Netherlands, using steam engines from England.

1885
2610 km of train track has been completed.

1892
Oil lamps changed to gas lighting, heating introduced shortly after

1908
Introduction of the first electric train.

1917
HIJSM and SS become the joint venture Nederlandse Spoorwegen - NS. Both parties remain independent.

1937
Fusion of HIJSM and SS into NS.

1939
NS stocks are acquired by the State.

1944-1945
Strike of the railway sector in the Netherlands.

1954 - Mat '54 electric train + 1st & 2nd class interior

1964 - Mat '64 electric train + 1st & 2nd class interior

1975 - SGM electric train + 1st & 2nd class interior

1980 - e-loc 1144 + ICR carriage 1st & 2nd class interior

1977/1983 - ICM + 1st & 2nd class interior

1984/1991 - DDM/DD-AR electric train + 1st & 2nd class

After the war
NS starts to rebuild with Marshall help.
The railway network is electrified further
Electric trains (130 km/u speed) are introduced.

60's
The car becomes achievable for the wider population
Transport of goods by train is strongly reduced through the rise of the truck and the closing of the coal mines. NS receives State compensation due to the public importance of the railways

70's
The amount of travelers has increased with 20% while 1.5x times the distance is travelled. The increasing money shortages are compensated by the State.

80's
Increasing amount of traffic jams and airspace is getting busier.
The environment becomes a priority.

1984
The first double-deck train (DDM) is built.

1992
Dutch government agrees with the autonomisation of NS.

1995
DDM had special bike storage built on the bottom floor (lasted till 2002).

1950 1975 1995

1956
Transition from three to two-class system in European trains

1958
The last steam train is taken out of service

1968
The current and characteristic NS logo is designed.

1969
'Spoorslag '70' is introduced: a company rescue plan with a new improved train schedule.

1986
First high-speed train in France

1988
Introduction future vision 'Rail 21' asking for further investment to expand the railway as road alternative.

1989
Development 'hufterproof' chairs by Emsta BV using AaBe fabric

1995
NS is split into NS Group and various railway task organisations (the latter unified in 2003 as ProRail)

1994 - VIRM electric train + 1st & 2nd class interior

1996 - DM'90 Diesel train + 1st class & standing carriage

2000 - eloc 1700 + ICRm 1st & 2nd class interior

2003 - SGMm electric train + 1st & 2nd class interior

2006 - ICMm + 1st & 2nd class interior

1995
NS becomes fully autonomous with a wide range of commercial activities

2000
Focus on two core activities:
1. Passenger travel (including train maintenance)
2. Junction development (exploitation of train stations and property development)

2002
Further finetuning company strategy:
1. Ride trains on time
2. Provide service and information
3. Contribute to social safety
4. Sufficient travel capacity
5. Provide clean trains and stations

2007
Drastic change train schedule, trains run with shorter intervals, and sprinter and intercity are introduced.

NS joins EU in sustainability targets as first big company

2007-2008
Focus on door-to-door journey:
- Updated website, with journey planner showing connecting local transport
- Start overhaul to create attractive station experience.

1995 2000 2010

Between 1995-2000
Activities outside the core business closed down (e.g. telecom)

2000
"Meer Man's Kaart" group card eliminated

2001
Service quality declines and the punctuality norm is failed, leading to customer complaints, strikes, and uncertainty about the company future.

2000-2006
Build of the highspeed railway (HSL)

> 2002
Acknowledgement I&W Ministery of backlog in rail maintenance. A 2 bln. investment in new trains is made, and future plan 'Benutten en Bouwen' is constructed

2004
New legislation framework for railway concessions. State invests in railway, but NS has to adopt a selective growth strategy.

2006
First power sockets built in trains. Initially only 1st class, but later also 2nd class

2008
NS acquires OV-fiets and introduces the OV scooter (available until 2014).

2009
Start introduction OV-chip card (first trial in 2006)

2009 - SLT electric train + 1st & 2nd class interior

2012 - V250 (Fyra) electric train + 1st & 2nd class interior

2012 - DDZ electric train + 1st & 2nd class interior

2015 - eloc NS 186 (Traxx) + ICRm 1st & 2nd class interior

2010
Reisplanner travel app is introduced and paper timetable books are not handed out anymore.

2011
Further finetuning company strategy:
1. Customer is King
2. We care for the environment
3. Europe as operation ground
4. Cost efficient
5. Focus on door-to-door journey
6. We make the difference together

2012
Financial crisis hits at NS

Provision of travel information transferred from ProRail to NS. On Board Information System (information screens) introduced in the train.

2013
New travel cards introduced:
- Group Retour ticket (encourage off-peak travel)
- NS business card (offer flexibility to become more attractive to businesses)

2014
Further enriching strategy:
1. Traveler stands on 1, 2 and 3
2. 'Door-to-door' collaboration
3. Europe empowers us

Additionally, there is more focus on train and station as social environment.

2010 — 2015

2009-2010
Train Wi-Fi (first trial 2007) and travel information displays (OBIS/RIS) installed

Sustainability into standard control cycle.

2011
I&W promises NS the 2015-2025 railway concession, giving opportunity for growth.

New concepts: Electric OV bike (available until 2015), social and study/work zones in train

2012
Frontal train collision, indicating max. capacity railway reached.

New concepts: DDZ lounge couches, Station2station (working at the station), NS zonetaxi, social media activity.

2012-2013
Delayed Fyra trains, (expected 2009), finally introduced, but pulled back shortly after due to structural technical problems.

2013-2014
Start tender for climate neutral energy, won by Eneco. This is the largest green energy contract in the Netherlands.

2014
'Raise train seat capacity to satisfaction' programme initiated

Placing OV-chipcard gates and opening first OV-service shops.

2016 - VIRMm electric train + 1st & 2nd class interior

2016 - NS FLIRT electric train + 1st & 2nd class/vestibule

2017 - SNG electric train + 1st class interior & vestibule

2021 - ICNG electric train exterior & interior impression

2015
Public confidence in NS decreased due to Fyra debacle and concession errors in Limburg. To restore image, NS aims to improve operational prestations and expand train frequencies.

2016
New strategy 'Spoorslags beter':
1. Better railway network prestations
2. World class stations
3. Better door-to-door journey

Corporate risk strategy made

2017
New train schedule and testing "Spoorboekloos Rijden" (6 trains/h)

All trains ride on green energy

2018
Important events:
- Chromium-VI case
- Integration AVG
- WW2 compensation
- HSL software issues
- Start Eurostar service

2019
NS is the largest mobility service and one of the largest employers in the Netherlands
New strategy 'Nederland duurzaam bereikbaar. Voor iedereen.'
1. Train and network of the future
2. Stations as a social mobility hub
3. Flexible & versatile travel with NS app

2015 — 2020

2015
- Customer serivce now available online 24/7
- New bike parking system
- Preparation toilet integration in SLT trains
- Focus on train accessibility and priority seating

2016
Train design:
- Lounge couches also in VIRMm
- Train seats for ICNG tested by consumer panel and colleagues
- Employment virtual reality for maintenance and training

2017
New concepts:
- Making valuable use of travel time
- Test alternative payment methods (e.g. NS Flex, pay by smartphone)

2018
New concepts:
- ZitplaatsZoeker (locate vacant seats)
- NS Flex: flexible travel and payment
- Start build of water points at stations

2019
- First experiment automated train operation
- 99% of materials train revision recycled
- Initiation coalition AndersReizen

2020
Corona hits with huge financial/ strategic impact on the company.

Interesting to see is that parallels can be drawn between new interior concepts and antique train interior. Figure 52 shows the interior design for the train of the future on the left, and the interiors of trains from 1874 and 1908 on the right. Of course the whole look and feel of the train is different, but elements such as the vaulted ceiling beams and half-high benches can already be found in trains dating back as far as 1874. Remarkably enough, the half-high benches were first introduced to limit the amount of lamps needed for one carriage: not only frugal, but also sustainable!

Figure 52: Design concept for the train of the future, compared to the interiors of trains from 1874 and 1908.

| C.2.5 Circularity roadblocks

There have been many circularity roadblocks mentioned through the report, such as the missing knowledge on material data and the tender obligation of NS. To structure the findings and summarize all known circularity roadblocks, the topic was discussed with Ilse de Vos van Eekeren, circularity expert at NS. Through her job, de Vos van Eekeren has a lot of experience with working on circularity projects and all the roadblocks involved. The roadblocks from the discussion were clustered and plotted along the train lifecycle (building – modernisation – end-of-life). This shows what the main roadblock themes are, and whether roadblocks apply to certain lifecycle phases or to the entire train lifecycle.

The final roadblock map can be seen in Figure 53. The found themes are Safety, Legislation, System, Design and Costs. Most themes are found in the System and Design clusters. However, the impact of each roadblock varies. For example, although there are not many different roadblocks within Safety, this is one of the most important roadblocks. This roadblock maps could be improved by also rating the impact or indicating the level of obstruction for each roadblock.

When considering the distribution of the roadblocks, it can be seen that most roadblocks are valid for the whole train lifecycle. However, these roadblocks might be encountered at different moments in time, and then it might be too late to change the origin of the problem. By presenting the roadblocks in an overview and considering them beforehand, even before the train is build, a large part of the roadblocks could be avoided. The remaining roadblocks require more structural change in for example company culture or company strategy.

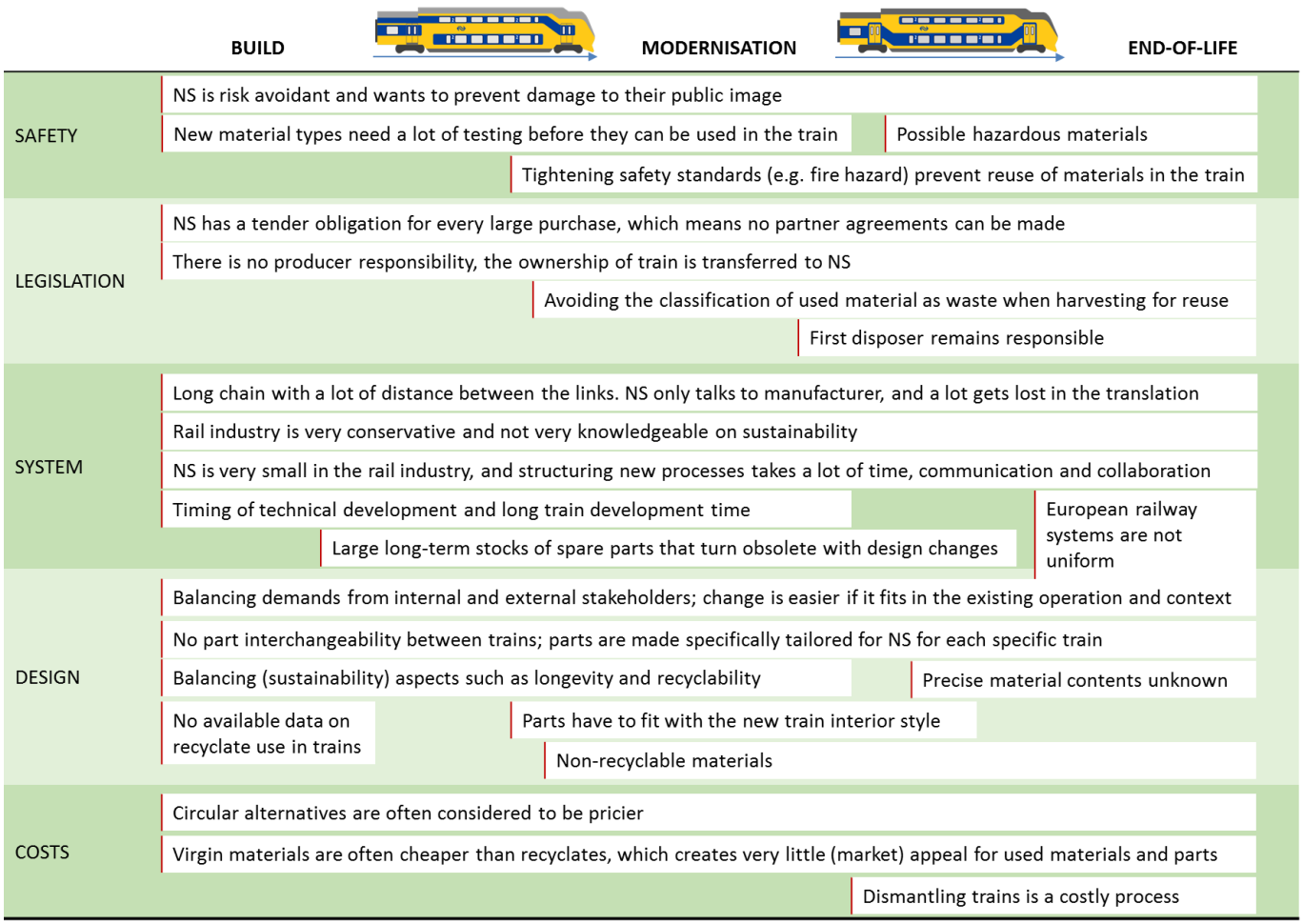


Figure 53: Roadblock map plotted against train lifecycle. Roadblocks validated with Ilse de Vos van Eekeren.

C.3 DESIGN

| C.3.1 Design vision

The future design vision was constructed in two-fold manner: firstly by investigating the design for the train of the future, and secondly by discussing with the members of the sustainability department what their desirable vision for the future is. When comparing these, the former is much more concrete and feasible compared to the latter. Therefore, the train of the future was applied as short-term vision and the discussion as a long-term vision. Below, the visions are described in more detail.

Short term (2030)

The new train interior (visualised in Figure 54) is comfortable, welcoming, accessible, and facilitates a wide range of activities. Within the design vision, two main themes can be discovered, as described below. On the whole, the first theme describes how the interior modules are shaped and applied to increase the traveling experience and raise customer satisfaction, whereas the second theme describes how these modules are created to realize a dynamic and circular train.

| 1. Travel time becomes your own time

Train interior has mainly been focused on creating seating capacity (Schiffer, 2018a). However, the train of the future should be more than a tube that transports you from A to B. It should be a comfortable place where you feel at home and where you can spend your time how you like it (Arne Lijbers, 2018). As the way people like to spend their travel time varies, a pallet of interior elements has been created based on analysis of activities and train traveller profiles (NS, n.d.). These have been combined into twelve interior modules, grouped into three different train zones: the relaxation zone, concentration zone and social zone. Each zone has its own interior and place within the train, based on activities and travel duration. For example, the social zone has 'stitting' places (in between standing in sitting) and is closer to the door, as it is aimed at shorter journeys. The concentration

zone is located deeper into the train, as it is aimed at longer train journeys (Schiffer, 2018a). This creates a dynamic travel landscape with different sit, 'stit' and standing places, where every traveller can find their ideal place, depending on activity, travel duration, travelling party size, luggage and required facilities (Mecanoo, 2019).

| 2. The train of the future is modular and circular

The design of the interior elements is based on a modular system which enables adjustability and variety per train car (NS, n.d.). By using a modular grid, the use of the available space can be optimized and the modules can be fit into the train like building blocks. The modules are suitable for every train type, and can be combined to give travellers more space in rush hour and a space to suit their demands outside rush hour (Schiffer, 2018b). The elements are fully circular, fabrics are reusable resources, and modules are easy to disassemble and interchange. This way, the train can respond to the demands of travellers and is prepared for the sustainable mobility of the future (Mecanoo, 2019). By designing in a modular and circular way, the concept is timeless and universal. Developing circular elements also increases product longevity and prevents waste (Veenendaal, 2018).

Figure 54: Concept interior for the train of the future (Mecanoo and Gispen, 2018).

Long term (2050)

The discussion with the employees of the sustainability department yielded a wide variety of insights and visions. These insights were clustered into the following general themes described below. The derived themes are along the same lines as the themes of the short-term vision. However, the themes of the short-term vision mainly describe the envisioned change within the train interior, while the long-term vision also describes the envisioned systematic operation of the train of future.

| 1. The train of the future is personalized

The train of the future connects to the traveller by offering seamless transitions along the door-to-door journey. It integrates alternative transport methods where possible to offer the best possible journey. The journey planner is updated to provide advice not only based on the journey but also on other important aspects such as speed, comfort and sustainability.

| 2. The train of the future is an experience

The train of the future should not only allow people to spend their time how they want it, but create an experience. This ensures that the train of the future can compete with the rising competition, Think for example about socialising or exercising in the train, or involving aspects outside the train, such as sightseeing in scenic areas. The traveller can enter the relevant train car/area based on their desires. In addition to the train, the station and station area can also be involved, such as creating green stations in car-free inner cities, as space efficiency is a strong argument for the train.

| 1. The train of the future is efficient

The train of the future makes not only efficient use of the available space, but also of the system. It works through the swarming of smaller units in a demand-driven system. Through the integration of smart technology, trains can run in much shorter intervals. This approach helps to reduce the amount of trains needed and optimize the seat occupancy in and out of rush hour.

Figure 55 gives an idea of how such a system could look like. In the upper right corner, the personalized travel planner allows customers to tailor their journey from home, and show more insight into the desires for specific journeys. Over time, the train cars will decrease in size and adopt a swarming approach, sending the parts of the trains only to the desired destinations, instead of occupying the whole length of the train to the end destination. The train cars will also have different styles, similar to the train zones of the short term vision. Think for example speed cars with high seating capacity, or comfort cars with working facilities. The swarming approach will allow quick transition between car types to meet demands, for example deploying more speed cars in rush hour and more comfort cars outside rush hour. The modular train interior will also allow to quickly reconfigure car types to fit seasonal or shifting demands.

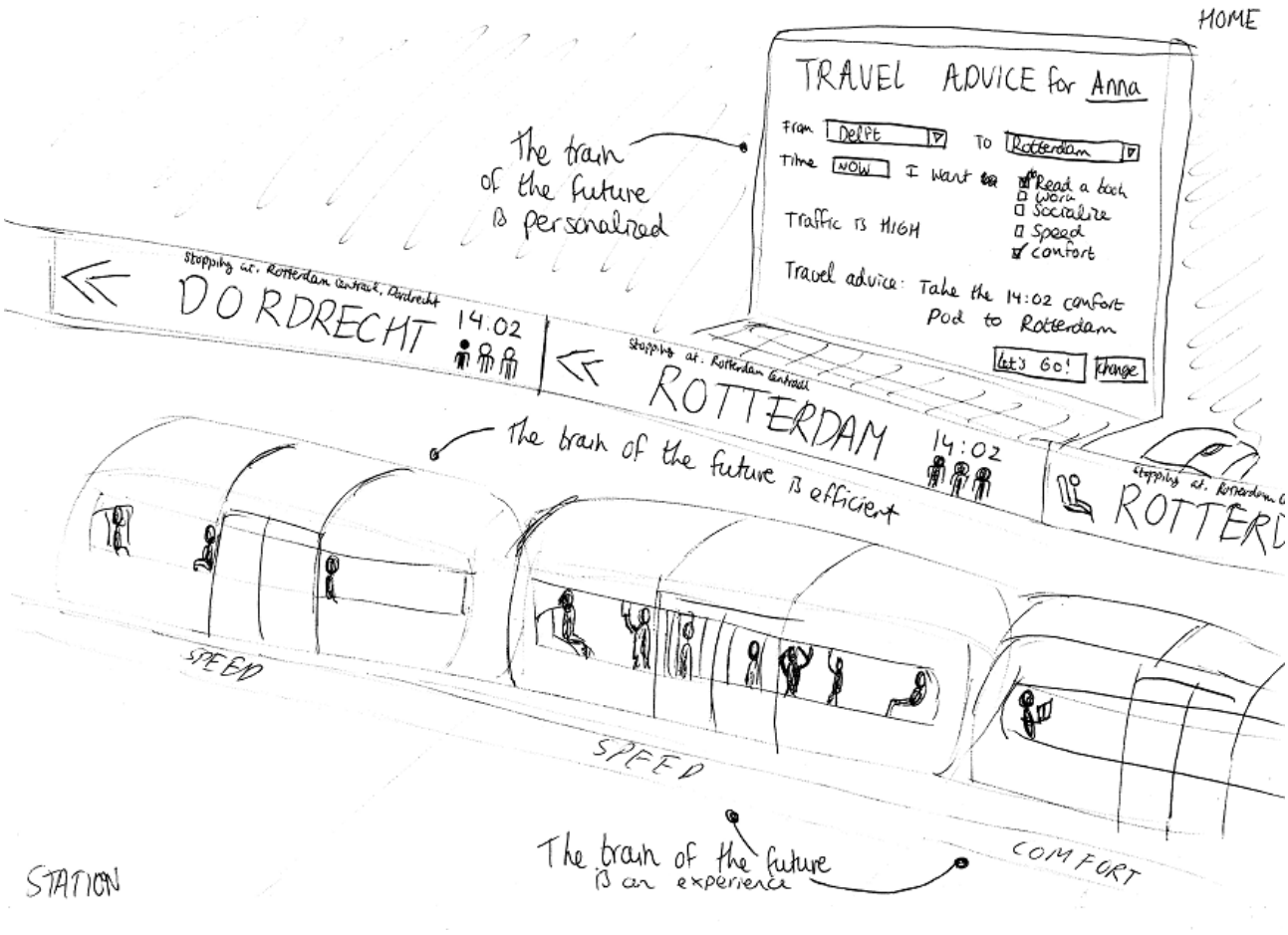


Figure 55: System concept vision constructed through interviews with NS employees

| C.3.2 Concept ideas

Just like in the previous iteration cycles, two design concepts ideas were created to further explore and validate the design vision. By designing a concept along the lines presented in the design vision, it becomes more clear whether the design vision is feasible. For the concept designs in this iteration, the short-term design vision was selected. Designing for this design vision best fits the earlier insights that change should be convincing and/or easy to implement.

| 1. Circular train seat

This concept is a reconfiguration of the standardized building element concept from the previous iteration cycle. Instead of focusing on the whole interior, this concept designs how one modular element could be built up from a single element. As seen in Figure 56, the current seating element uses many different shapes in its construction. The circularity of this module can be increased further by building this element using one shape of cushion. Additionally, the adjustability of the seat could be realised by shaping the chair not through the shape of the cushions, but by placing shaping elements behind the cushion or shaping the back panel. The materialisation of the elements should

also be circular, such as by replacing the PU foam with latex foam, which is made from a natural resource, compostable, and far more durable.

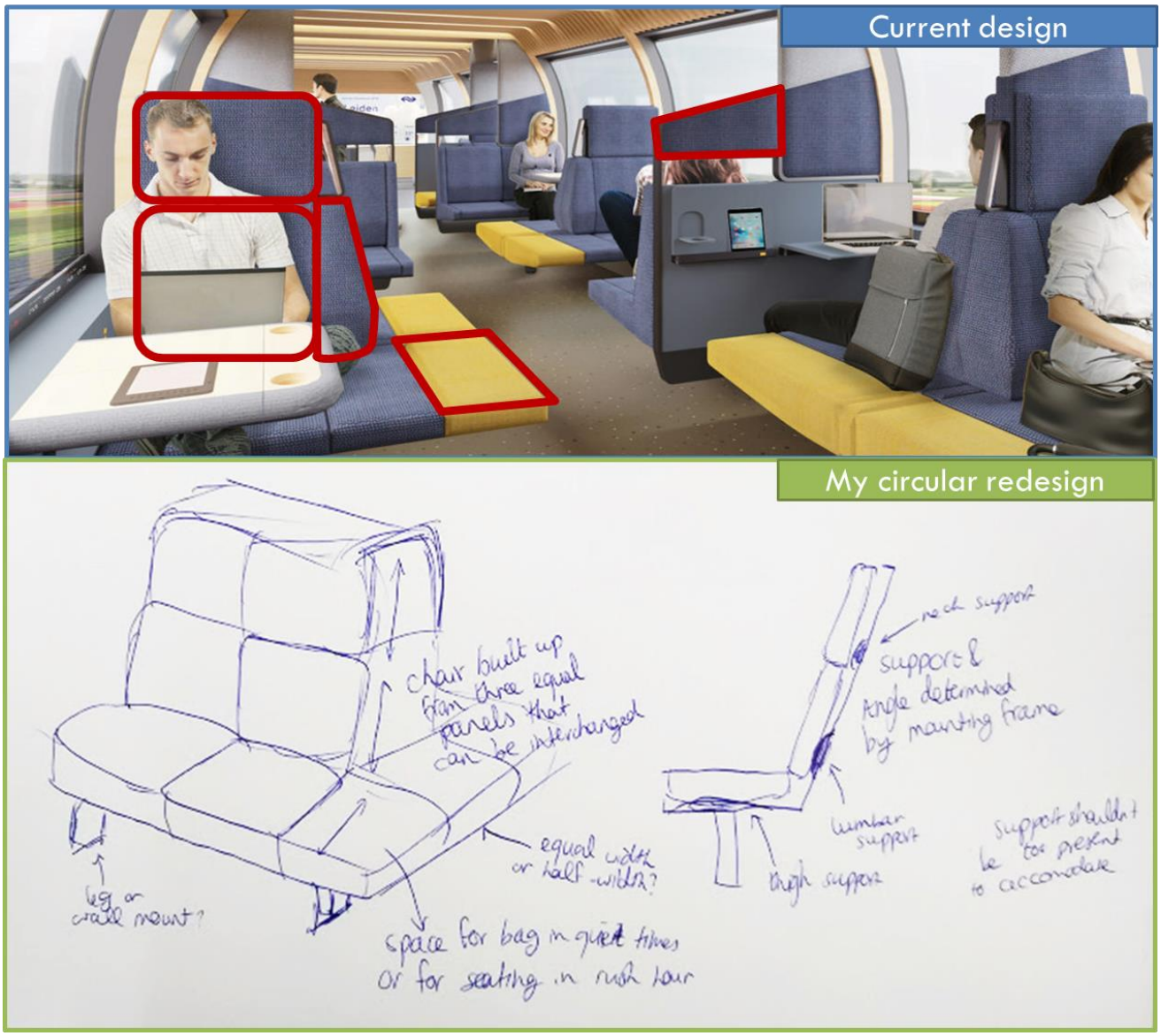


Figure 56: Circular single-shape redesign of the modular seating element

| 2. Circular wall panel

This concept is a circular reconfiguration of the current wall panel in the train. At the moment, this panel is made from glass fibre reinforced polyester, a composite material which is practically impossible to reconfigure, reshape or recycle at the end-of-life. This redesign makes use of honeycomb core sandwich material, which is a mono-material and thus much easier to recycle. To advance this concept further onto the Ladder van Lansink, the design includes a reversible glue layer between the sandwich layers. This is based on the current concept configuration of the train floor, which combines the wooden underframe and rubber top layer with a glue that can be separated again after use by force. If this is applicable on the floors, it should also be possible for use on the wall panels. This wall panel and its materialisation can serve to show how circular reconfiguration of the train can be created, thus reducing a large part of the non-recyclable material flow. It can be implemented into the current company context through the tender specifications, or as input for the Sustainable Material Handbook as mentioned before in A.5.

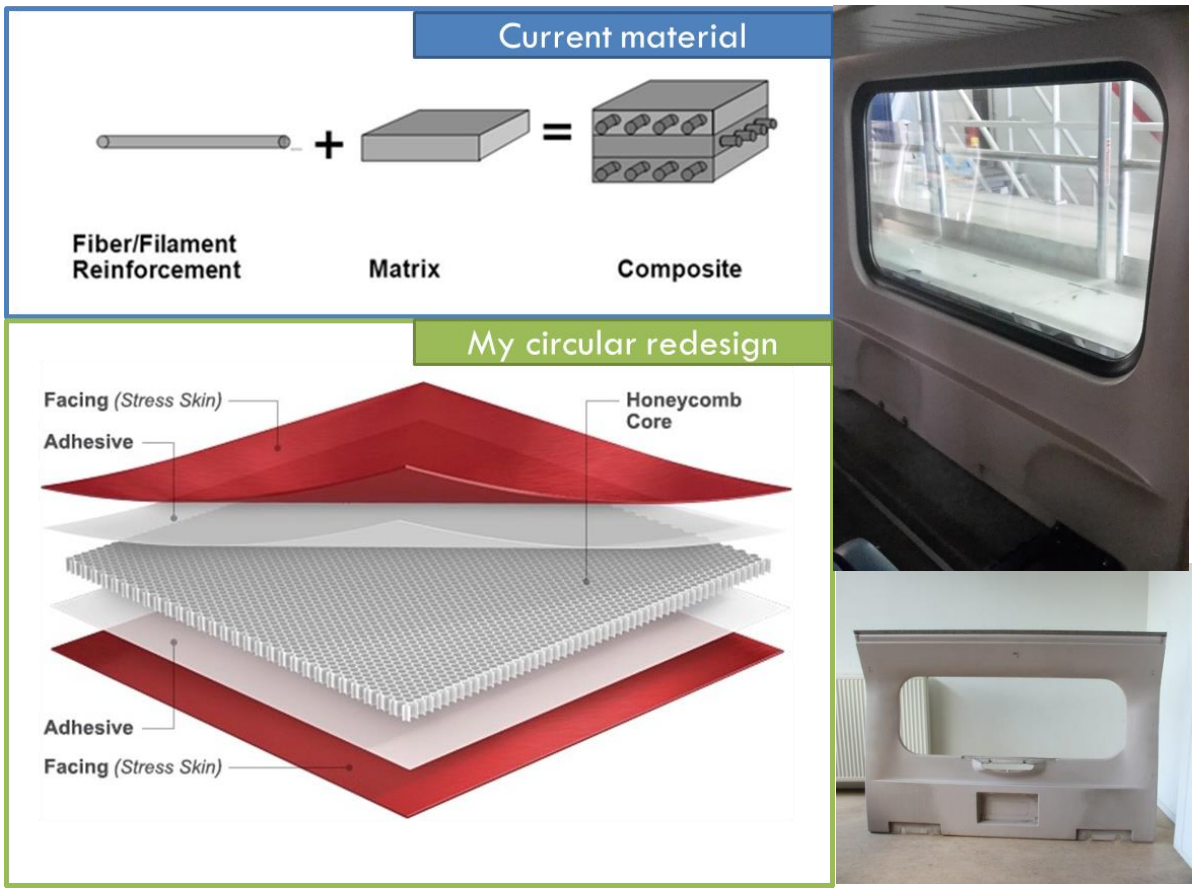


Figure 57: Circular (material) redesign of the composite wall panel, with on the right the current wall panels

| C.3.3 Concept choice

The concept choice for this iteration cycle and the final project concept is shown in Table 10. This overview compares the concepts on ten different criteria, which have been derived from the project reflections and in discussion with colleagues of the NS sustainable entrepreneuring department.

Table 10: Concept choice for third iteration cycle and final project concept

Selection criteria	Concept 1: Seating element				Concept 2: Wall panel			
1. The product reduces the material use compared to the current design								
2. The product is feasible to realize								
3. The product fits in the current NS processes and company structure								
4. The product fits in the future vision								
5. The product has a minimal environmental impact during use								
6. The product enables a circular EOL *(at least recycling but preferably higher on Ladder van Lansink)*								
7. The product contributes to the frontrunner position of NS								
8. The product is innovative								
9. The product is visible to the consumer								

The concept most suitable to work out in this project combines impact with feasibility while fitting in the current NS company structure and the future mobility context. Furthermore, to contribute to the sustainable frontrunner position and company image, the concept should be innovative and ideally also in the public eye. The overview shows that concept 2 is the most favourable in consideration of these criteria.

| C.3.4 Summary of findings

When looking at the trend pattern web, the only connection between designing around people's needs and circular rethink is "Guilt-free consumption". This can be an indicator of why it can be so difficult to push for sustainable development, as on first sight there is little to gain regarding for example customer satisfaction or financial benefits. Therefore, when exploring sustainable solutions, it can be very useful to also research the benefits for other aspects as well in order to make a strong argument.

From the material flows it can be concluded that trains have already a high recycling percentage due to the high weight of recyclable metals, and the low weight of non-recyclable composites. However, composites are very difficult to reuse due to their thermoset nature. When looking at the sustainable projects listed in the first iteration cycle, the current strategy of NS is to invest in development of projects and methods to process their end-of-life composite materials in a second application, such as railway sleepers or construction elements. In my opinion, this is a good strategy for the material currently still in trains, but it is not a strategy to hold onto for future trains. Of course, recycling of composite materials can progress a lot between now and the outflow of the next train, but waiting for this technical development does not fit the sustainable frontrunner position that NS currently upholds. Instead, the focus should be on choosing and developing sustainable alternatives. It helps for the circular reconfiguration of trains to know what exactly you are working with. However, the configuration of the data sets used for the material flows varies widely, with not all lists indicating the parts that the materials originate from. Not knowing the location of materials makes it difficult construct a detailed material documentation, and limits the overall overview to a blank material flow. This blank flow gives little indication to determine which train elements need circular reconfiguration.

The historical timeline is a valuable tool to decide and validate the design pacing for the circular reconfiguration and the design concept of this project. It shows that in order to be implemented in the train, it needs to have a good fit with the current context. However, subtle changes have less problem getting implemented. This confirms the notion of the second iteration cycle that ideally the concept would change not much in performance, handling and appearance, yet make a big impact. Alternatively, change in the system could be balanced out with additional benefits, such as the lounge couches that fit more occupants in rush hour while allowing spacious seating outside rush hour. The chosen concept of this iteration cycle gives an example of how this change could be realized.

1.1.1 Stakeholder feedback

IDE feedback

An example of a reversible adhesive would be Niaga, which is a glue that loses its adhesive power at high temperatures. For the concept selection and design criteria, write down where these criteria came from, make it transparent. Discuss the results and feedback with the sustainability team, but also with relevant departments such as engineering and cleaning. For the project the design can serve as a way to develop the design vision instead of being a finished product. Also, other industries such as the airplane industry could serve as inspiration, as these are also integrating ergonomics, comfort and lightweight aspects into the interior.

NS feedback

It is recommendable to check the data overviews and insights back in the business. For example the bogies are already partly made of recycled materials. For the side wall concept it can be handy to compare this with the current origin and price to make a stronger argument. Regarding concept

choice, the side wall is most favourable. The chairs are relevant too, but already a whole team is involved in redesigning this aspect and it will be difficult to contribute to this, whereas the wall panels haven't gotten much focus yet. This makes that the innovation on the side walls will be bigger. This concept could also contribute to the design of future trains, as the tender application for the DDNG has a process agreement with the train supplier to optimize the side walls, floor and seats. For this it would be useful to see in what way sandwich composites are already applied in train & relevant industries (e.g. aviation, automotive). And have these already been combined with reversible adhesive? The strong point of the circular train seat compared to the side wall panel is that it is more visible to consumers. So ideally, the final concept would also consider how its sustainability could be communicated.

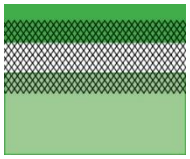
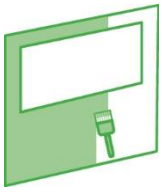
C.4 REFLECTION

This iteration cycle embodied a lot of research work and yielded a lot of valuable insights. The previous two iteration cycles helped me to configure the right project focus for this research. The previous design concepts also helped to choose the right design direction. I am happy with my design direction and final concept choice, as I feel it balances viability and feasibility for both realization and implication very well with the desired environmental impact. The next phase is not a research and design iteration, but serves to work out the chosen concept direction into a concept design. The configuration options for this design will be explored to come to a final concept recommendation. This concept can be worked out further in future NS projects such as the sustainable train material handbook, or serve as inspiration for finding sustainable alternatives for non-recyclable materials such as glass fibre composite.

D DESIGN CONFIGURATION

The proposed design for the panel construction was made by researching the different configuration options as shown in Table 11. As all these aspects cover a lot of sub-options and also influence each other, it is difficult to say what the best option is. Therefore, this chapter will give more insight into the considerations made to come to the design proposal.

Table 11: Morphological chart showing all the different configuration options for the honeycomb side wall panel

	Options			
	1	**2**	**3**	**4**
Material	Aluminium  Corex, AluNID, Alucoil	Plastic  Econcore, Armacell, Tubus Waben	Cellulose  Niaga	Alternative skin  (e.g. HPL, GFRP)
Shape	Flat 	Soft bend 	Hard bend 	Complex 
Shaping	None	Machining 	Forming 	Flexible core 
Adhesive	Epoxy 	Niaga 	Thermal welding 	
Lamination	None 	PP film 	PET fleece 	
Finish	Paint 	Foil 		

D.1 MATERIAL

This paragraph compares different material options on performance, circularity and price. Table 12 gives a material data overview of the honeycomb cores. This overview was constructed by combining numerous datasheets from honeycomb core manufacturers within Europe (see Appendix G). The materials included in this data overview are aluminium 3000 and 5000 alloy series, and plastics PP and rPET. There are also honeycombs available constructed from PLA, PC, PEI, but these materials are less suitable for the wall panel. PLA has a temperature resistance between -25 to +55 °C , which is too low for use in the train. PC is aimed at flow efficiency such as refrigerators, Although PEI has good high-temperature resistance and is not as flammable as other plastics, it is very expensive at 15 €/kg (see Table 13). Additionally, DSM Niaga has developed cellulose panels, but these are not yet proven within similar applications, so no comparable data is available. This is why PC, PEI and cellulose are omitted from the overview.

Table 12: Honeycomb material data overview, data retrieved from honeycomb material data sheets from Corex, Cellite, AluNID, Alucoil, Compocel and Alucore, Econcore, Tubus Waben, Nidaplast

	Aluminium	**Plastic**
Manufacturers/ brands in Europe (selection)	Corex (UK): Corex & Superflex TRB Lightweight structures (UK): Cellite™ AluNID (ES): aluNID ® Alucoil (ES): larcore ® CEL COMPONENTS (IT): Compocel® AL FR 3A Composites (DE): ALUCORE®	Econcore (BE): ThermHex (PP, rPET & PLA) Tubus Waben (DE): Tubus Honeycomb Nidaplast (FR): Nidaplast 8 CEL COMPONENTS (IT): Polypropylene honeycomb
	Performance bare core	
Core material	Aluminium 3000 alloy and 5000 alloy	PP, rPET, (PLA, PC, PEI)
Cell size	1.6 - 19.1 mm	3.0 - 9.6 mm (8.0 mm most common)
Density[1]	Low: 20 - 147 kg/m3 High: 27 - 262 kg/m3	80 - 120 kg/m3
Compressive strength[1,2]	Low: 0.35 - 10.1 MPa / 0.6 - 10.5 MPa High: 0.6 - >14 MPa / 0.85 - >15 MPa *(plain/stabilized)*	PP: 1.2 - 2.95 MPa rPET: 1.4 - 2.5 MPa
Shear strength[1,2]	Low: 0.34 - 5.86 MPa / 0.24 - 3.59 MPa High:0.66 - >6.76 MPa / 0.41 - >3.79 MPa *(L/W direction)*	PP: 0.3/0.5 MPa rPET: 0.6 - 1.1 MPa (L direction)
Crush Strength[1,2]	Low: 0.15 - 5.07 MPa High: 0.25 - > 7.09 MPa	
	Panel construction	
Panel size (L x W)	Standard: 2500 x 1250 mm 3000 x 1250/1500 mm. Range: 2000 x up to 18000 mm ± 0.12-30 mm	Standard: 2500 x 1200/1220 Range: 1000 - 2900 mm x 850 - 1400 mm ± 4 mm
Core thickness	Generally ≥ 3-4 mm ± 0.1-0.3 mm	PP: 5 - 100 mm (every tenth) ± 0.35 mm PET: 3.5 - 28.0 mm, PLA: 3 - 30 mm
Foil thickness	Low: 50 µm High: 70 µm	
Skin thickness	Generally 0.5/1.0 mm, up to 5 mm	Comparable to aluminium
Skin material	Various, mostly aluminium	Various, non-specific
	Safety and qualification	
Temperature resistance	-40 to +150 °C (but properties will reduce when temperature in-/decreases)	PP: -30 to +80 °C (short-term 140 °C) rPET: -40 to +160 °C (short-term 180 °C)
Fire safety	EN 45545 hazard level HL3	EN 45545, EN 13-501
	Circularity	
Recyclability of material	Recyclable without loss of quality at industrial scale	PP and rPET are both recyclable at industrial scale
Recycled content	No recycled content reported, but it is feasible	PP: no recycled content reported rPET: 95% recycled (post-consumer bottles)
	Price	
Price	Expensive	Less expensive

[1] Low and High depend on the foil thickness that is used to construct the honeycomb core (50 or 70 µm).

[2] Compression, shear and crush strength for most dense version not available.

| D.1.1 Material performance

Figure 58: Foam core (left) and honeycomb (right). Retrieved from Carbon-core (Carbon-Core Corporation, 2020)

When considering the required strength for the panel, it is important to note that train wall interior panels serve as cladding against the carbody. It is not a structural weight-bearing element, and therefore does not have much regulation on what forces it needs to withstand. The only primary load requirements described in UNIFE TecRec (UNIFE, 2014) are that it needs to withstand "a concentrated perpendicular load of 2,0 kN applied over a symmetric area of not more than 0.01 m2 which may occur at any position on the surface" and "a pressure of 2,0 kPa applied over the entire surface". Of course, the resistance towards these forces also depends on the shape and skin type of the panels, but both the aluminium and plastic honeycomb should be able to withstand this when considering that the material data in Table 12 only covers the core. These scores will only improve after adding the skin. Another thing to consider is that, as opposed to foam cores, honey comb cores do not have a catastrophic failure mode as illustrated in Figure 58 (Carbon-Core Corporation, 2020).

More important are the fire safety requirements. Key parameters used here are flame spread, ignitability, heat release, smoke opacity and toxicity. Aluminium is a very suitable material for this application, as it is incombustible and has a melting point around 535 - 639 ˚C (CES Edupack 2019, 2019; Corex Honeycomb, 2020).
Plastics are more troublesome. These materials are highly flammable and the melting point is much lower: 150 - 175 ˚C for PP and 212 - 265 ˚C for PET (CES Edupack 2019, 2019). This means that these materials would need flame retardant additives in order to pass the test. In this case, PEI would be more suitable, as it is self-extinguishing (CES Edupack 2019, 2019).

| D.1.2 Circularity

The only honeycomb material that reports on circular inflow for the material is the rPET material, which uses 95% post-consumer PET bottles. However, the potential for circular inflow is much larger. Aluminium can be recycled easily without virtually any loss of material quality (European Aluminium, 2015) and PP was also tested to move through multiple recycling cycles with only a small decrease in strength (Weckström, 2012). Of course, recycling is only the last stop for the panel. It would be more interesting to see how the panel could be reused or repurposed. Both aluminium and plastic honeycomb panels can be reshaped after use, which means they could be reconfigured to fit a new train shape or a new application outside the train. For reuse, it should be looked into what material would better fit the changing train environment, while also considering the product lifetime. For repurpose outside the train, the market size and interest for used panels should be looked into to see what material type would be the most promising to repurpose.

| D.1.3 Price category

There is not much openly available about the price of the panels. Corex does have a webshop to order panel testers, but this is not representative for the price of the final product. To give an indication of the price, the material prices per kg can be compared. These prices were retrieved from CES Edupack 2019 (CES Edupack 2019, 2019), Level 2 (and Level 3 for PEI, unfilled).

Table 13: Material prices per kg

Aluminium: 2.02 – 2.18 €/kg	PP: 1.19 – 1.23 €/kg PET: 1.13 – 1.31 €/kg	*PLA: 2.42 – 3.18 €/kg* *PC: 2.76 – 3.03 €/kg* *PEI: 15 €/kg*

The price overview in Table 13 shows that aluminium is generally pricier than PP and PET, but cheaper than PLA, PC and PEI. Ward Mosmuller of DSM Niaga confirmed that aluminium panels would be considerably pricier (Personal communication, 2020, July 28). The production process is also of large

influence. Honeycombs that can be produced continuously are much cheaper to produce, as stated by Econcore for their PP honeycombs (Econcore, n.d.).

D.2 SHAPE

This paragraph will look at the shapes for train interior side panels by comparing current train interiors. It also includes the implications of choosing a specific panel shape.

| D.2.1 Train interior fashion

Table 14 gives an overview of the walls in current train series. The newer Flirt and SNG are omitted from this overview, as no drawings or side wall drawings could be found in the database during this project. The train wall type overview gives an indication of the shape of the interior wall. This shape is created by tracing the contours of the front view and side view of a side wall in the technical drawings retrieved from Infor PLM (NS database). Details were simplified while tracing, such as small radii around windows or corners or hooks for attachment. Any bends of the side profile to the right are towards the train interior, and vice versa. Also important to note is that there are many different panel variations in a single train type. However, this approach is sufficient when only looking at the overall panel shape. The measurements (rounded to tens) indicate the size of the panel front view, which is the composite panel section around one window (except for SGMm) from the floor up to the luggage racks.

Table 14: Analysis of train wall types and measurements in current train fleet

SGMm  Flat ~3100-3400 x 1510	**ICMm/ICRm**  Soft bend ~2400 x 1370 mm	**SLT**  Flat ~2220 x 1330	
DDZ **(lower floor)**  Flat ~1630 x 1410	**DDZ** **(upper floor)**  Hard bend ~1620 x 1220	**VIRM/VIRMm** **(lower floor)**  Flat/complex ~1900 x 1470	**VIRM/VIRMm** **(upper floor)**  Hard bend/complex 1930 x 1330

The overview in Table 14 shows that most sidewall panels have a quite simple shape. The main fashion trend is to build flat or soft bend side walls for single deck trains, and flat and hard bend side walls for double deck trains. Only the VIRM/VIRMm has a complex side contour, as this train type makes use of garbage bins that are placed within the side wall. Regardless of whether this contour could be achieved with honeycomb panels, it is preferred not to do so as it would only increase costs. Additionally, as newer train types such as Flirt and SNG do not make use of these type of garbage bins, it is unlikely that this contour would be needed.

When looking at the panel measurements, it can be seen that most fall within the 2000 x 1500 mm range. The ICMm/ICRm and SLT are only slightly wider, and SGM has wider panels as it has a separate strip running beneath two windows. Standard honeycomb panel sizes are 2500 x 1250 and 3000 x 1250/1500 for aluminium and 2500 x 1200/1220 for plastic honeycombs (see paragraph D.1). Not all panels therefore fit the standard panel size, but it is very feasible to create the desired shape without needing extensive custom sizing.

| D.2.2 Flat panels for fabrication ease

A side note to consider when choosing the shape is that flat panels are easier to press and to finish and/or foil. This is because a flat panel can be placed on a vacuum table, whereas curved panels would require special clamps or moulds to be secured (Niaga, personal communication, 2020, July 28). This could be partially counteracted by making the backside of the panel flat, so that it can be clamped via vacuum suction on that side. The added benefit for creating flat and non-complex shapes would also be that it's easier to reuse or repurpose in another application.

| D.2.3 Bended/complex panels for design and space optimisation

The benefits for choosing a bended or complex panel shape would be that the side wall can be tailored to the design of the train and the car body shape. This is especially important when considering double decker trains, as using flat walls could considerably impact the available space in the train. Still, the fabrication possibilities for the panel should be taken into account to limit the production costs of the panel. This means a bended panel shape is preferred as opposed to complex.

| D.2.4 Second product lifecycle within and outside the train.

The reuse of the panel should not be limited just to train modernisation. It would be more interesting to consider a second lifecycle as well as a prolonged first use cycle. This could either be in another train series, or within another industry. The shape of the panel can then be adjusted to meet the requirements of the envisioned second lifecycle. Below, reuse of the panel in other train series, the construction industry and furniture industry is discussed.

Considering the reuse of panels in other train series, the SGM configuration seems an interesting choice. By running the side walls in two sections, larger panel pieces can be used to easier fit new a new train. The panel shape would preferably be flat or softly bended, as this shape is easier to reshape to fit a new train shape. Separating the window frame part means that when fitting the panels in other trains with a different window size, only the top partition with the windows would need replacement instead of the whole panel. Of course, this could also be achieved by cutting off the window section, but this would lead to a smaller bottom partition (only one-window width instead of two).

Although reusing the panels in other train series would be the preferable application, it is uncertain whether this option can be legally realized as NS is bound by tender contracts for the building of new trains. Therefore, it is recommendable to also consider repurpose applications outside the train. To gauge interest for reusing the panels in the construction industry, I contacted New Horizons, an urban mining collective that harvests materials from buildings for reuse. From director Alex Verkuijlen I received the reply that the reuse possibilities for honeycomb materials depend on many factors, such as listed in Table 15 (Personal communication, 2020, July 16). From his reply there can be concluded that having a larger bottom section as described above would also be more interesting as this increases the size of the available material. However, the availability of the material would be an issue. More research and collaboration would be needed to find how this issue can be overcome. Verkuijlen recommended me to contact their partner Stiho for further help.

Table 15: Factors to consider when designing for reuse in the building industry

Material	What material is it made from? What is the footprint?
Measurements	The building industry is used to work with big measurements and tailor those to size. How smaller the available material, the smaller the amount of possible applications
Availability	If the material is made specifically for trains, the availability will be very low. It will per definition not be suitable, as the effort for convincing the building industry to use the material will not outweigh the guarantee of supply.
Compatibility	How does the material react or how does the material processing compare to the other building materials used?

Another application with a lower production requirement would be to reuse the material as a desktop. NS already has a collaboration with Gispen to produce desks out of train ceiling plates. When looking at the measurement requirements for a desk, ergonomic desk norm EN 527-1 describes that an ergonomic desk top is at least 80 cm deep and 120 cm wide, with an ideal width of 160 cm. As can be seen in paragraph| D.2.1, all current wall panel measurements have a width of minimally 160 cm. The depth of the desk is more problematic however. The bottom section of the SGMm panel has a height of roughly 50 cm, which is too small for use as a desktop. The other wall panels don't have much wider bottom sections. A possibility would be to produce a children's desk: the measurements of these desks at IKEA vary between 73-128 cm width and 50-58 cm depth (IKEA, 2020). Another option would be a side table, book case or closet. However, additional research and collaboration would be required to see if sufficient market would be available to offset the furniture outside NS.

As found in this section, there is not yet a ready-to-go application that fits the side wall panel. Still, generally seen it would be easier to make the width of the bottom partition a multiple of the height, for example 300 x 50 cm. This way, it becomes easier to create square or rectangular shapes for furniture with only minimal offcuts. Facilitating reuse of the material between the windows is more tricky as the space between the windows is generally limited; around 50-70 cm wide and around 85 cm height. Also for most series, except ICMm/ICRm, this space is divided in half by the panel edges. This makes this section less interesting. However, combining the SGMm and ICRm/ICMm configuration as shown in Figure 59 on the left would optimize the available material size for that area. This way, for example a shelf for in a closet or book case could be created from this material section. Other shelves could be created from the wall section above the wall panel behind the luggage rack or by cutting up the bottom section. Another configuration option that minimalizes the waste generated when a window shape is changed would be placing separate panels between the window frames as presented in Figure 59 on the right. However, this would increase the amount of mounting profiles and thus material and labour needed, resulting in higher costs.

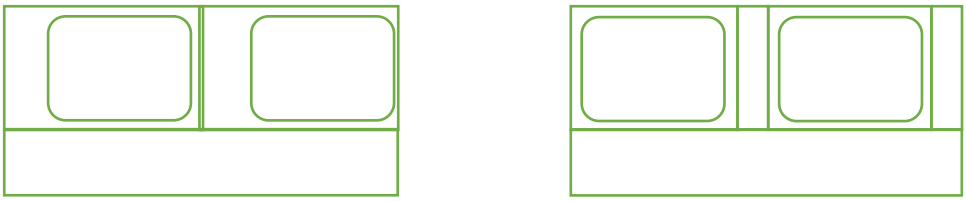


Figure 59: Panel configurations that)combine SGMm and ICMm/ICRm layout (left) and minimize window frame area (right)

D.3 SHAPING

As the shaping is highly dependent on the chosen shape, this paragraph will discuss both the shaping possibilities for both material types and the pros and cons for each shaping option.

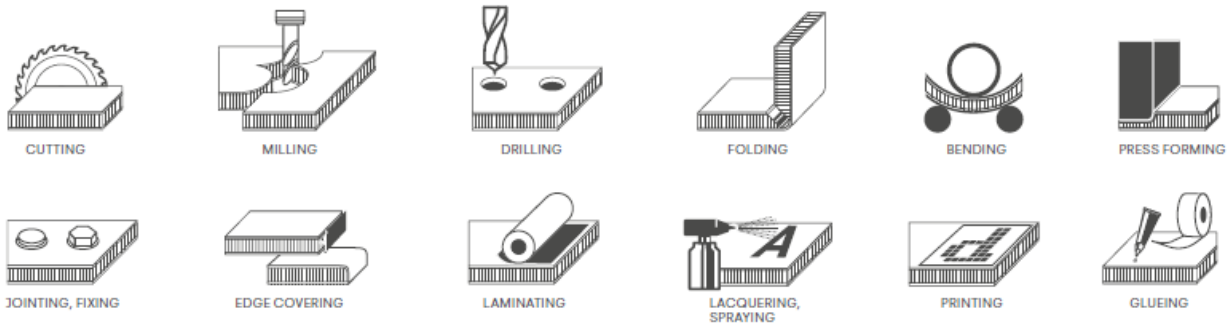


Figure 60: Shaping options for aluminium honeycomb panels, retrieved from the Alucore brochure (3A Composites, 2019)

Aluminium honeycomb can be machined to form a complex surface with the use of high speed routers. Some single curvature contours can be machined on to an unexpanded slice before expansion (Corex Honeycomb, 2020). Figure 60 shows that additionally, panels can also shaped using forming methods such as folding, bending, and press forming. Another option is to use flexible

aluminium core, such as Superflex by Corex. By adapting the cell geometry, the aluminium honeycomb can bend and flex. The resulting flexible honeycomb has the same properties as the standard hexagonal cell shaped aluminium honeycomb, and can be used for curved panels, spherical, cylindrical and organic shapes (Corex Honeycomb, 2020). Of course, shapes can also be created by joining multiple panels/shapes, for example through the use of mounting profiles.

For plastic honeycombs the reported shaping options are mainly cold moulding and warm moulding. Cold moulding allows honeycombs with low thicknesses to be shaped in large radii at room temperature. The shaping is done by applying pressure or vacuum on a sandwich element that has been placed and fixed into a shaping tool. The new shape is retained by hardening the resin or adhesive (TUBUS WABEN GmbH & Co. KG). For warm moulding, the thermoplastic honeycomb (with or without thermoplastic skin) is first heated through an oven, infrared radiation or heated mould. Then, the panel is shaped in the mould, after which it is cooled. The process is reversible, and can be repeated through reheating and reshaping, as long as thermal decomposition is not caused in the material due to overheating. Additionally, the temperature should allow moulding but not melting as this will cause the honeycomb to lose its structure (TUBUS WABEN GmbH & Co. KG; Plascore, Inc., 2018). To summarize, the options are to use no or minimal shaping, machining, forming or a flexible honeycomb to achieve the desired shape. Below, the pros and cons for these options are discussed.

| D.3.1 No or minimal shaping

If the panel is flat, it will require no or only minimal shaping. Examples of shaping that can be done for these panels are rounding the edges towards the window, or creating a ridge for holding the panel in the profiles that fit the panel against the car body of the train. These shapes can be created using cutting or milling techniques on either expanded or unexpanded slices.

+ Minimal effort
- Limited form freedom

| D.3.2 Machining

Expanded and unexpanded aluminium panels can be machined to create curves. However, when large curvature contours are created, a lot of material will have to be removed, leading to large material losses. There is no mention of machining contours for plastic honeycomb cores.

+ Some form freedom
- Machining large curvatures means more material loss.

| D.3.3 Forming

Both aluminium and plastic honeycombs can be shaped through forming, bending and press forming. As this is done after the skin is added, the material losses are reduced. However, the structural and/or temperature impact of the process should be taken into consideration.

+ Great form freedom
+ Reduced material losses
+ Easier to add skin
- Possible impact one panel performance

| D.3.4 Flexible core

By using flexible aluminium honeycombs, extensive form freedom can be achieved, such as curved panels, spherical, cylindrical and organic shapes. However, this will likely come with a higher price tag.

+ Extensive form freedom
- Likely more expensive

D.4 ADHESIVE

This paragraph will discuss the adhesive options that adhere the skin to the honeycomb material. For this, the material, performance, reversibility and recyclability will be discussed.

| D.4.1 Adhesive type

For honeycomb panels, there are multiple adhesive types that can be used. Examples of common types are structural adhesives such as polyurethane or epoxy, or hot melt adhesive films (Nidaplast). The standard type for most adhesives is epoxy (Ruben Rulf, personal communication, 2020, June 29). For honeycombs, it is mostly a high performance epoxy film adhesive (80° C service temperature; TRB Lightweight Structures Ltd.) as this is easier to adhere to the honeycomb). However, epoxy is a toxic substance, which should be avoided when designing for sustainability (Niaga, personal communication, 2020, July 28). Another interesting adhesive is Niaga due to its reversibility (see section | D.4.3). This adhesive is made from polyester. It is not yet used for aluminium or plastic honeycombs, but it has been used for cellulose honeycomb panels, carpets and mattresses (Niaga, personal communication, 2020, July 28). For plastic honeycombs, welding is also an option for attaching skins to cores (TUBUS WABEN GmbH & Co. KG). However, this means that the layers cannot be separated again after use. It should therefore only be applied when the core and skin are made of the same material to ensure that the panel can be recycled as a whole.

| D.4.2 Adhesive performance

In general, tough and resilient adhesive systems are preferred for honeycomb panels as opposed to a brittle-hard adhesive system, as resilient systems score better in the so-called peel tests that test the skin-core adhesion. The common adhesives such as epoxy have already proven themselves regarding strength and use in honeycomb panels. For Niaga, additional testing would be required to see if it would be suitable for use within the train. However, as it is also used in panels and mattresses, it is highly likely that it will have sufficient strength. Furthermore, Niaga is made from polyester, which doesn't burn or develop black smoke, thus reducing suffocation dangers and increasing its fire safety performance. It is uncertain what the performance of welding is, but if this is done well, the joint will become part of the material. It will therefore be unlikely to yield to peeling or to have a different fire safety degree than the core/skin material.

| D.4.3 Adhesive reversibility and recyclability

Epoxy, other common adhesives and welding all form (near) irreversible connections. This means that the only way to separate the main materials will be by pulling them apart with considerable force or by cutting them loose. With common adhesives, this will mean that there will be residues left behind on the material, which impacts the recyclability. Welds are even more difficult to separate, again leading to material residues if the panel is not made from mono-materials. Additionally, epoxy adhesives are non-recyclable (Niaga, personal communication, 2020, July 28).

Niaga on the other hand can be reversed and by the application of heat/energy. This means the panels can be readjusted or reconstructed if needed, and that parts of the product can be replaced. Also, when separating the panels, Niaga leaves no residues to ensure clean recycling. Also important to consider is that the best recyclability is achieved by creating mono-materials, as separation is difficult and expensive. In case of Niaga, the adhesive is made from polyester, so combining with polyester would give a mono-material (personal communication, 2020, July 28).

D.5 LAMINATION

Lamination of the cores is often mentioned in combination with (mainly plastic) honeycomb panels. This lamination is done by attaching and (thermally) connecting a PP film and/or polyester fleece layer to the honeycomb core (see Figure 61). The PP film is applied when using liquid resins. It prevents resin from leaking into the honeycomb, safeguarding uniformity of the mechanical performance and keeping the honeycomb free of resin. The fleece layer is used as an adhesive for further processing by creating a surface for improved bonding with the core when attaching the honeycomb panel skins (TUBUS WABEN GmbH & Co. KG, n.d.; EconCore N.V., 2020).

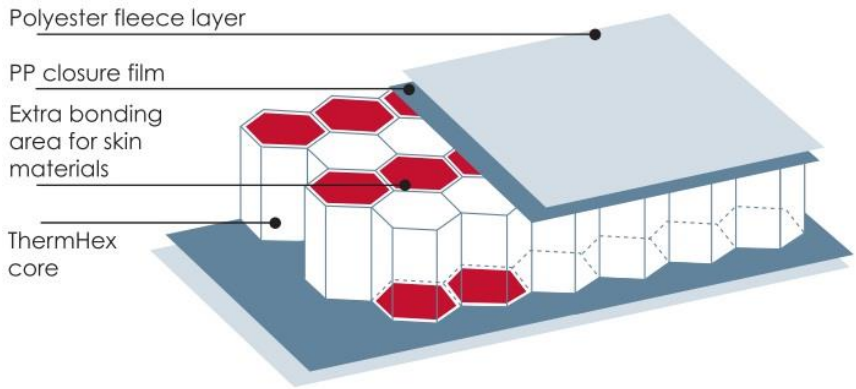


Figure 61: Application of lamination layers, reproduced from EconCore (EconCore N.V., 2020)

When creating a circular product, it is important to use as little material as possible and to create reversible connections (Niaga, Personal communication, 2020, July 28). As using a resin glue is non-reversible, it is not recommendable to use this glue type, which means a PP film layer has little use. Niaga also confirmed that no additional lamination is required when using their glue (Personal communication Ward Mosmuller, Niaga, 2020, July 28). As the fleece layer also increases material use, it should be avoided. Lamination should only be used when it improves product circularity, for example by reducing use of materials/adhesives or improving ease of disassembly.

More interesting than using lamination would be to consider optimal application of the adhesive. Generally, for the sake of convenience, the adhesive was applied to the skin and the honeycomb was placed in the adhesive; this is also called embedding. However, this means more than 90% of the adhesive is in the wrong place, which increases adhesive costs and unnecessarily raises the flammable mass. In most cases the bond strength is impaired too. It is therefore important that honeycomb edges are properly embedded in the adhesive and the adhesive itself is ductile. A system to improve the adhesion is to use a slit adhesive film that expands after heat activation, shown in Figure 62. Application in this manner concentrates the adhesive around the honeycomb edges, thus limiting the amount of glue used. Additionally, the slit film system yields much better peel strengths and similar flexural strength and creep resistance compared to conventional embedding. The challenge is to match the adhesive network to the honeycomb structure. Although process optimisation is time-consuming for industrial use, the results make it worth-while (Jud, 2012).

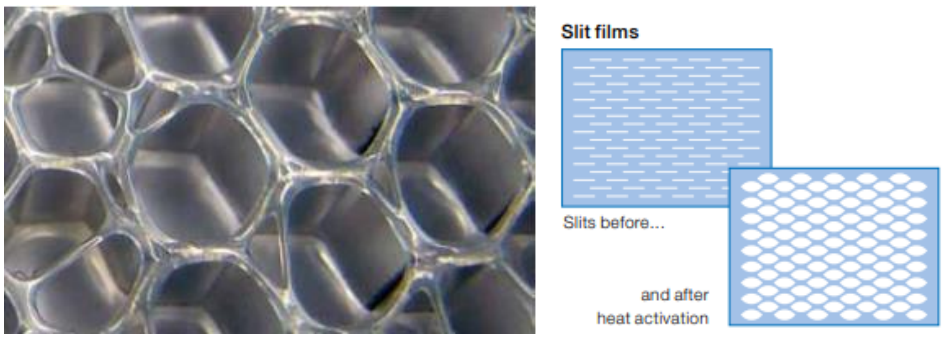


Figure 62: Film adhesive concentrated around the edges of aluminium honeycomb (left) and slit film expansion (right)

D.6 FINISH

Traditionally, paint is used to colour the side wall panels in the train. A different way to finish the wall panels would be to use foil. Aalse Dijkstra, cleaning engineer of NS, informed me on the current application of foil in NS trains (Personal communication, 2020, July 15). Below, the differences of paint and foil regarding application and reconfiguration, fire safety, cleaning and vandalism, and sustainability will be discussed.

| D.6.1 Applying and reconfiguring paint and foil

Painting is a laborious process which can yield toxic fumes. A bio-based paint such as Decovery could be considered to improve sustainability, but even then painting is an irreversible process. The only way to remove paint is by sanding it off. This yields paint dust, which could be seen as micro plastics (Ward Mosmuller, Niaga, Personal communication, 2020, July 28). Additionally, the dust can be toxic, for example when the paint contains chromium-6. Also, as stated in section **Fout! Verwijzingsbron niet gevonden.**, sanding and repainting is often not possible at modernisation, which means the whole part cannot be reused.

The foil, made of polyester, is currently mainly used on train exteriors. It has also been applied in the interior of some trains, such as in toilets and on the partition walls (between seating and balcony) of the ICM train. The foil can be applied easily, and has no shape restrictions. After use, the foil can be removed again. On the exterior of trains, often a transparent foil is used over a paint system. This is done on recommendation of the manufacturer for the preservation of the train. However, there are also trains in Norway that do not use paint underneath the foil (Aalse Dijkstra, NS, Personal communication, 2020, July 28). Additionally, the train interior is for example not exposed to rain. Using a coloured foil would therefore be preferably to reduce the materials and chemicals used. Additionally, this means that readjusting the panel appearance at modernisation could be as easy as swapping the foil for another colour or pattern.

| D.6.2 Fire resistance of paint and foil

Paint is currently used, and adheres to safety regulations due to the right additives. For the interior use of foil, fire safety is the biggest reason why it is not applied yet. It has taken 20 years before using the foil on train exteriors was permitted. This is not due to the fire safety of the foil itself: the polyester foil is not flammable but self-extinguishing, and only leaves a small burn mark. Instead, the issue is that paint, wood or other materials underneath the foil keep burning (Ward Mosmuller, Niaga, Personal communication, 2020, July 28). This could be avoided by not using paint and choosing a non-flammable material for the honeycomb skin.

| D.6.3 Panel cleaning and vandalism

When applied to the exterior, paint is quite high maintenance. It needs to be washed often, and once every sixty days the paint needs to be cleaned with oxalic acid, which is a harmful substance. Additionally, paint is very vulnerable to vandalism such as graffiti (Aalse Dijkstra, NS, Personal communication, 2020, July 28). Cleaning graffiti means that the train is taken out of service, and also a lot of materials and chemicals are used to remove it. The train is placed on an absorption layer while the graffiti is washed off with aggressive chemicals. Afterwards, the whole layer is thrown away (Ilse de Vos van Eekeren, Personal communication).

A foil exterior on the other hand has to be cleaned only half as much, and it does not need treatment with oxalic acid. When cleaning graffiti, the train still needs to be taken out of service, but cleaning graffiti off foil takes only half the time (Aalse Dijkstra, NS, Personal communication, 2020, July 28). When translating these insights towards interior use, foil would be easier to clean and could use less aggressive cleaning agents.
The only way that the foil was damaged during testing was with a knife, but almost no finishing systems are resistant to this. Also, no knife damage has been encountered during tests with foil in train toilets (Aalse Dijkstra, NS, Personal communication, 2020, July 28).

| D.6.4 Longevity and recyclability of foil and paint

To compare the lifetime of both paint and foil, it is interesting to look at the ICMm trains. Twelve years ago, most ICMm trains were put in foil, but a couple remained painted in order to compare. In those twelve years, the foil has not suffered any damage or loss of colour. The painted trains on the other hand have been repainted three times already (Aalse Dijkstra, NS, Personal communication, 2020, July 28). This makes foil the more durable option. Also, when considering recyclability, paint is also not the preferred option. As stated in section | D.6.1, paint can only be removed through

sanding. The resulting dust is not recyclable. The foil on the other hand can be removed, and is taken back by the supplier for recycling (Aalse Dijkstra, NS, Personal communication, 2020, July 28).

D.7 SUMMARY

Table 16 shows an overview of the most important findings for each option.

Table 16: Summary of findings for each configuration option

Category	*1*	*2*	*3*	*4*
Material	Aluminium	Plastic		
	+ Non-flammable + Already applied in trains - Expensive	+ Cheaper - Needs additives for required fire resistance - Not yet applied in trains		
Shape	Flat	Soft bend	Hard bend	Complex
	+ Easier to produce, reuse and repurpose - Limited form-freedom	+ Side wall can be tailored to train design/shape - Increased production costs	+ Side wall can be tailored to train design/shape - Increased production costs	+ Side wall can be tailored to train design/shape and integrated parts - Highly increased production costs
Shaping	No/minimal	Machining	Forming	Flexible core
	+ Minimal effort - Limited form freedom	+ More form freedom - Material loss	+ More form freedom - Affects skin integrity	+ Extensive form freedom - Possibly expensive
Adhesive	Epoxy	Niaga	Thermal weld	
	+ Industry standard - Irreversible and non-recyclable	+ Reversible and recyclable - Needs testing	+ No additional materials used - Irreversible	
Lamination	PP film	Fleece	None	Optimal glue film
	+ Prevents resin leaking into core - Adds materials	+ Improves bonding (surface) of the core - Adds materials	+ No materials used	+ Improves core adhesion and performance - Optimization process needed
Finish	Paint	Foil		
	+ Industry standard - Irreversible and non-recyclable	+ Durable, reversible and recyclable - Needs testing		

E DESIGN CRITERIA

Below is a list of design criteria for the sidewall design. This list is constructed from my own estimates and insights through involvement at NS, and by selecting the relevant criteria from regulation documentation such as TecRec, as cited in the list. This list has not been validated and the design has not been checked against the requirements, but it helped me to get a better view on which aspects were relevant and on what requirements are currently in place.

1. Performance
   - 1.1. The wall product must allow mounting onto the car body shell.
   - 1.2. The wall product design must (be able to be adjusted to) allow the mounting of interior elements (e.g. seat elements, luggage racks). This includes both sufficient strength and stiffness as well as the fitting of inserts for mounting.
2. Environment
   - 2.1. The product must be able to function between general temperatures between 19 and 26 degrees.
   - 2.2. The product must not be significantly affected by cabin temperatures between 0 and 40 degrees Celsius.
   - 2.3. The product performance and colour must not degrade significantly/critically under the influence of general cabin humidity.
   - 2.4. The product performance and colour must not degrade significantly/critically under the influence of (indirect) sunlight.
   - 2.5. The product must not leach hazardous substances to the environment in the prescribed production, usage and end-of-life processing scenarios.
3. Life in service/Product lifespan
   - 3.1. The product is a non-loaded passive train interior part, so it will see low usage intensity.
   - 3.2. The product must have a general lifespan of 15-20 years.
   - 3.3. The product must be able to be produced for as long as the train is in use.
4. Maintenance
   - 4.1. The product must be able to remove from the car body to allow servicing of the windows.
   - 4.2. The product must be able to be dismantled from the car body in the general maintenance and service workshops of NS.
   - 4.3. Dismantling the product from the car body should take less than 10 minutes with two people.
   - 4.4. The product must be able to be cleaned with water and general cleaning agent.
5. Target product cost
   - 5.1. The cost of the product must not exceed ???
6. Transport
   - 6.1. The products must be able to be transported with an efficiency of at least 50%.
   - 6.2. The products must be able to be withstand general transport and handling with minimal packaging. This includes both functional and cosmetic/visual effects.
7. Packaging
   - 7.1. The products must be delivered with minimal and/or reusable packaging.
8. Quantity
   - 8.1. The amount of products produced is the amount required for the train production and for the necessary spare stock. This will be around 12 products for a single-deck train car and 23 products for a double-deck train car, plus negligible stock. With generally 500-700 train cars in a train series, this means a batch size of between 6000 to 16100 products.
9. Production facilities
   - 9.1. The main production of the product will be outsourced; only minimal adjustment should be made in the maintenance workshop when installing a product (e.g. when replacing/repairing).
10. Size and weight
    - 10.1. The product thickness must not exceed the 20 mm width (excluding protrusions for the mounting of interior elements) to allow enough space for other interior elements.

10.2. The product weight must not exceed the current product weight of ... kg?
10.3. The product must fit within the expected train cabin interior measurements.
10.4. The space normally used by seated or standing passengers or staff shall be considered to be limited to a maximum height of 1950 mm above floor level in standing areas and up to a maximum height of 1680 mm above floor level in seating areas. In seating areas the assumed seat width shall be at least 450 mm centred relative to each seat. The upper corners of the seated space envelope may be assumed to be radiused to a maximum value of 225 mm. *(NOTE: These parameters are based on the PRM TSI requirements for headroom in seated areas.)*

11. Aesthetic, appearance and finish
    11.1. The product must fit in the envisioned future train design aesthetics.
    11.2. The product must have a timeless/neutral appearance.
    11.3. The product must have a (visually) smooth surface for easy cleaning.
12. Materials
    12.1. The product must make use of lightweight materials.
    12.2. The product must consist of materials that are able to be recycled at the end of life using conventional (industrial scale) process methods.
    12.3. The product must not make use of any hazardous materials, such as asbestos, chromium-VI and any other materials that are on the REACH list or in any other way forbidden, or expected to be forbidden soon.
    12.4. Standards, rules and regulations
    12.5. The product and mounting profile must make use of standard mounting hardware (screws/nuts and bolts/inserts/etc.).
13. Ergonomics
    13.1. Max. 2 people should be needed to lift the panel.
    13.2. Max. 2 people should be able to mount the product with both an ergonomic working posture.
14. Reliability
    14.1. The product must not fail under general usage conditions.
    14.2. The panel must survive a fall of up to 1 m.
    14.3. The panel must fail in a consistent way in expected collision scenarios.
15. Storage
    15.1. The products must be able to be transported with an efficiency of at least 50%.
    15.2. The product must be able to be stored in general storage conditions (no additional heating/cooling and ambient atmosphere) without product degradation.
16. Testing
    16.1. The product must be tested for fire safety as described in the EN 45545-2 standard
    16.2. The following tests are used to measure how the product compares to the product requirements.
        16.2.1. TO1 Oxygen Index
        16.2.2. 03 Flue gas density
        16.2.3. T12 Smoke toxicity
    16.3. Key parameters that are measured include flame spread, ignitability, heat release, smoke opacity and toxicity. Having passed the tests, the product is given approval according to EN 45545-2 for use in trains.
    16.4. The product must be tested for primary load.
    16.5. The product must be tested through a secondary impact review as described in UNIFE TecRec. The secondary impact review should be based on an examination using the definitions in this document and recommended criteria set out in 6.2.2.
    16.6. Areas which are accessible to passengers and staff in normal service shall be subject to a secondary impact review to examine the general features and detailing of the vehicle interior considering the risk of injury due to secondary impact against surfaces or items.
    16.7. The design and installation of the interior shall be examined for potentially aggressive features with respect to:

16.7.1. Exposed corners and edges.
16.7.2. Recesses.
16.7.3. Protrusions.
16.8. The following may be omitted from the secondary impact review:
16.8.1. Items shielded by another item when potential impact is considered in longitudinal, lateral or vertical directions.
16.8.2. Items which cannot be contacted by a 100 mm diameter sphere.
17. Safety
17.1. The product must adhere to the EN 45545-2 standard fire safety standards for train interior.
17.2. The product must adhere the primary load requirements as described in UNIFE TecRec,
17.2.1. Interior doors (with the exceptions of hinged doors which do not lock or latch) and partitions, in any areas of such items which are not glazed, shall withstand the following proof loads applied independently:
17.2.2. A concentrated perpendicular load of 2,0 kN applied over a symmetric area of not more than 0.01 m2 which may occur at any position on the surface
17.2.3. A pressure of 2,0 kPa applied over the entire surface.
17.2.4. The positions where the concentrated loads are the most critical shall be determined. The analysis shall consider the maximum stresses in the door structures or partitions due to bending and stresses at mounting points and any other locations where stress concentrations could occur due to local details or changes in shape or form.
17.2.5. The proof loads shall be applied to partition faces which are fully or partly exposed to the vehicle interior. Where both faces of a partition are exposed to the vehicle interior the proof loads shall be applied to each face independently.
NOTE 1: The proof load requirements do not apply to areas of partitions which are completely shielded by other items, for example seats or luggage stacks. A partition is required however to withstand any loads transferred to it by such items.
17.2.6. Where partitions are fitted with trim panels, it is permissible for the specified proof loads acting on the trim panels to be considered as ultimate loads for these items.
NOTE 2: Where trim panels are used, the specified loadings are to be treated as proof loads by the underlying structure of the partition assembly. In terms of secondary impact, provided that hard spots or abrupt changes in stiffness can be avoided, the implied panel flexibility would generally be considered beneficial to passengers in the event of a collision.
17.2.7. Where seats are attached directly to partitions or the seat backs are placed sufficiently close to partitions, luggage stacks or other seat backs to allow them to be contacted under proof load conditions, the partition, luggage stacks or adjacent seats shall withstand without significant permanent deformation loads that are transferred from the affected seats when subjected to the specified seat proof loads.
17.3. In case of a collision, the product must resist deformation or deform/collapse in a controlled way that poses no risk to the passengers and staff inside the train.
18. No excessive deformation towards the interior of the train;
19. No forming/exposing of sharp edges
20. The product must adhere to the following requirements for interior features with injury potential, as described in UNIFE TecRec.
20.1. Exposed edges in rail vehicle interiors
20.1.1. Only exposed rigid edges which can be contacted by a 100 mm diameter sphere shall be considered. Edges of components which are not directly exposed (for example sheet metal fabrications beneath seats) shall be de-burred or chamfered to give smooth edge profiles.
20.1.2. In differentiating between an external and an internal edge, where a panel edge fits up against another element to form a step or a recess that edge shall be considered to be internal (for example where rebated panel joints are used).

20.1.3. A rigid edge shall be considered to be one using material with a Shore A hardness greater than 50.

20.1.4. With the exception of glass edges, there shall be no exposed rigid external edges where the predominant radii (i.e. ignoring transition and blending radii) are less than 3 mm.

20.1.5. For exposed rigid external edges, where the edge projects not more than 3,2 mm from the adjacent surfaces, the requirements for minimum radii shall not apply, provided that the height of the projection is not more than half its width and its edges are blunted.

20.1.6. There is no restriction on the use of alternatives to the specified or recommended dimensions where evidence of their suitability can be presented in terms of injury potential. The specified dimensions may be used as the basis for comparison.

20.2. Edge profile recommendations

20.2.1. For solid or framed partitions, where there are no exposed glass edges, the predominant corner radii (i.e. ignoring transition and blending radii) for all exposed rigid external edges should be:

20.2.2. For longitudinal partitions at least 10 mm and the exposed edge should have a minimum overall thickness of 35 mm unless the edge is shielded by a grab pole, grab rail or other feature.

20.2.3. For transverse partitions at least 5 mm, and the exposed edge should have a minimum overall thickness of 20 mm unless the edge is shielded by a grab pole, grab rail or other feature.

20.2.4. Partitions with exposed glass edges should be orientated in a transverse direction. Partitions with exposed glass edges shall not be orientated in a longitudinal direction. NOTE 1: Shielding provided by a grab pole, grab rail or the use of a resilient edge profile would no longer result in an exposed edge.

20.2.5. Exposed rigid external edges of luggage stacks and exposed rigid external edges on the undersides of overhead luggage racks should have radii of at least 10 mm, subject to the application of the formulae permitted by 6.2.2.3.

20.2.6. Exposed rigid external edges of interior panelling (for example corner joints between walls) should have radii of at least 10 mm, subject to the application of the formulae permitted by 6.2.2.3.

20.3. Projecting items

20.3.1. Wherever possible, concealed fasteners should be used to minimise the risk of injury due to secondary impact. The type and location of fasteners which are flush fitting or which are not concealed (for example countersunk, domed or standard screws or rivets) should be assessed to ensure the risk of secondary impact injuries is controlled.

21. Reuse, recycling

21.1. The product must allow reuse/remounting after demounting the panel.

21.2. The amount of different product varieties must be minimized/optimized to limit the amount of needed spare stock.

21.3. Different materials in the product must be able to be separated using conventional/industrial scale processing methods (e.g. heat, pressure, force) at the end of life.

21.4. Connections/adhesives in the product and for mounting the product must be reversible.

21.5. The product, product materials and mounting materials must be able to be recycled at the end-of-life.

F TREND ANALYSIS

Cluster – algemene trend	**1 – gevolg**	**2 – actie**	**3 – resultaat/visie**
Verstedelijking Tot 2030 zet de verstedelijking door (MA).	- Sterkere stedelijke concentratie (MG) Door verstedelijking komt er meer verdichting in steden (MA)	- Het is van belang dat ruimtelijke ontwikkeling en groei van mobiliteit hand in hand gaan (I&W)	Knooppunten als sociale hub (I&W)
	De verstedelijking zorgt voor een kortere afstand per verplaatsing. (MA)	- Gemeenten voeren meer maatregelen in voor autoluwe binnensteden. Dit stimuleert aandeel lopen, fietsen, OV en multimodaal (MA) - Rol fiets wordt belangrijker (MG) - Meer fietsgebruik, zowel traditioneel als elektrisch (MG) *Fijnmazige steden, Kosten laag, flexibiliteit hoog, Toename actieradius, Gezondheid als driver*	Ontwikkeling nieuwe types (micro)mobiliteit Binnenstedelijke bereikbaarheid vs interstedelijke agglomeratie (MG)
	- Steden worden steeds drukker, veel regio's kampen met krimp (NS) In rurale gebieden zal het voorzieningen niveau terug lopen wat leidt tot langere afstand per verplaatsing	In gebieden waar het niet rendabel is om vaste OV-lijnen te rijden, wordt in toenemende mate vraaggestuurde OV-systemen geintroduceerd (MA)	Vraaggestuurde mobiliteit
	- Mass transit zal blijven bestaan en zelfs groeien in de steden en op drukke verbindingen Mobiliteit groeit de komende decennia tot 2040 nog met max 40%	Door flexwerken kan de mobiliteit in de spits verder dalen (MA)	24-uurs economie zonder spits (MG)
Toenemende technologische maakbaarheid tegen steeds lagere kosten (MG)	- Fysieke en digitale verbinding in mobiliteit (NS)	- Ontwikkeling van autonoom vervoer gaat snel richting 2030 (MA)	Autonoom vervoer (NS, MA) - Zelfrijdende auto

- Living technologies - Zero marginal cost society *Hierbij is de mens een costante factor: "iets meer dan een uur per dag mobiel" (MG)*	- Internet of Things – meer mensen en meer dingen zijn verbonden zijn verbonden met het internet (MG)	Nieuwe vervoerstypes zoals autonome en verbonden voertuigen (Capgemini)	*De zelfrijdende auto kan invloed hebben op de gebruikerskosten van verschillende vormen van mobiliteit waaronder de trein (NS)*
		Voertuigen en infrastructuur worden steeds meer connected	Slimme infrastructuur - Beschikbare ruimte kan steeds efficienter worden benut Gebruik, monitoring en onderhoud is beter in te plannen
	Elektrisch reizen wint terrein (NS)	- Sterke stijging in verkoop van E-bike/speedpedelec als alternatief voor de auto voor afstanden tot 15-25 km (MA) - Meer gebruik elektrische fiets, stijging in: o Aantal afgelegde km's o Beschikbaar aantal fietsen Verdere ontwikkeling elektrische auto (FIXME bron)	Elektrische/emissievrije mobiliteit *De trein is al heel duurzaam, we moeten ons richten op emissievrij (I&W)*
	- Ontwikkeling van nieuwe typen voertuigen (MG) - Eisen aan kwaliteit voor vervoer zorgt dat transport snel stiller wordt	- Vormen van micromobiliteit (oa steps en hoverboards) nemen toe en zullen mobiliteit toegankelijker maken (met name voor korte afstanden (MA) Meer mobiliteitsdiensten die zich richten op snel, flexibel en gemakkelijk vervoer (MG)	Mobiliteit As A Service (MA, Capgemini) Maatwerk voor elke rit (MG) Veiligheid en luxe vs de funfactor (MG)

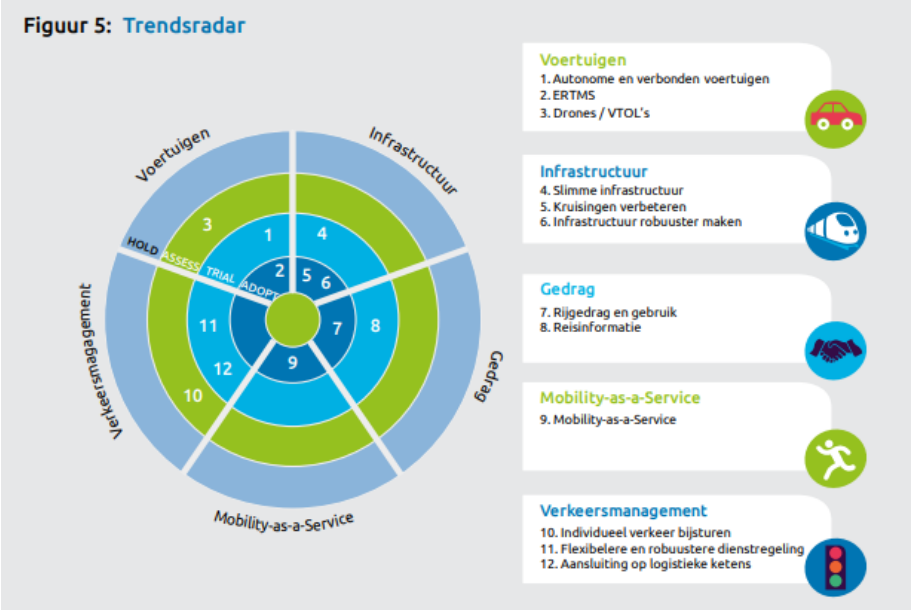
Veranderende mobiliteitsbehoefte *De bevolking groeit, wordt gemiddeld ouder, en het aantal mensen met een ziekte neemt toe (MA, MG)*	- Reizigers verwachten steeds meer een gepersonaliseerde deur-tot-deurreis (NS) Deur tot deurreis wordt belangrijker (I&W)	Naadloos aansluiten van OV/vraaggestuurde mobiliteit (I&W)	Mobiliteit As A Service (MA, Capgemini) Maatwerk voor elke rit (MG) Veiligheid en luxe vs de funfactor (MG)
	We stellen andere eisen aan de beschikbaarheid van vervoersmiddelen: gebruik/delen is belangrijker dan bezit (NS)	- Richting 2030 wordt toegang tot producten en diensten belangrijker dan eigendom. Deelsystemen worden populairder (MA) *"Zolang we in Nederland een studentenjaarkaart hebben voor het OV, zal de nieuwe Uber niet in Nederland worden uitgevonden" (MG)*	
Gezondheid en milieu zijn onderwerpen die de kwaliteit van leven beinvloeden (MG)	- Meer bewustwording over duurzaamheid (MA) *"In Europa is er de tendens om voor voor reizen < 700 de veel duurzamere trein te nemen in plaats van het vliegtuig" (NS)*	- Klimaatakkoord; afspraken voor reductie van uitstoot broeikasgassen o 49% in 2030 (NS) 40% in 2030 en 80-95% reductie in 2050 van CO2 op Europees niveau (MG)	- Transport van fossiele brandstoffen zal afnemen (MA) - Verschuiving van fossiele brandstoffen naar andere, schone en hernieuwbare brandstoffen (MG)
		Binnen het personenvervoer neemt het aantal duurzame opties toe, oa OV (MA)	Het OV emissievrij (I&W)

1.1 MOBILITY

General:

- https://www.rijksoverheid.nl/onderwerpen/openbaar-vervoer/betere-verbindingen-openbaar-vervoer/ov-in-de-toekomst
- https://magazines.rijksoverheid.nl/ienw/ienw-specials/2019/07/index
- https://magazines.rijksoverheid.nl/ienw/ienw-specials/2019/07/eerste-stappen-overzicht-acties
- https://magazines.rijksoverheid.nl/ienw/ienw-specials/2019/07/een-grote-en-urgente-opgave

- https://mobiliteit.gelderland.nl/Trends/default.aspx
- https://www.capgemini.com/nl-nl/wp-content/uploads/sites/7/2018/04/trends-in-mobility-2018-report.pdf



- file:///H:/My%20Documents/Studie/Relevante%20documenten%20(nader%20te%20orderen)/r-2013-16.pdf
  - Outlooks for the future that were made in the Netherlands and in Europe indicate the unanimous opinion
    - that Europe will continue to age,
    - urbanization will continue,
    - information and communication technology will continue to develop
    - climate will change.
    - There is more disagreement about changes in lifestyle, globalization and economic growth.
  - Also based on the general trends mentioned above, expectations are that
    - car ownership will decrease and the trend will be towards car rental when it is necessary. This is illustrated by a concept such as for example Green Wheels.
    - The number of senior road users will increase.

  - Furthermore, it is to be expected that as a result of urbanization more trips will be made by public transport and by two-wheelers and (electrically) powered two-wheelers.
  - Measures taken to reduce CO2 emissions will result in lighter vehicles.
  - The emergence of high-speed train connections in Europe will lead to a decline in the use of plane as well as car for medium distances.
  - Furthermore, one of the European objectives is to bring about a shift towards freight transport by rail and over water. This could result in a decrease in road freight transport. The construction throughout Europe of what are known as corridors will result in a larger road network.
  - All the above trends in the field of traffic and transport have consequences for road safety. Part of the developments is favourable for road safety (e.g. increased use of public transport) and part is not (e.g. more senior road users).
  - The technological developments, especially those in information and communication technology, are expected to change the driving task dramatically. In addition to systems warning the driver (e.g. equipment that gives a warning signal when the driver is tired, or warns when vehicles are approaching on collision course), more and more devices will be introduced that take over driver tasks, like braking to prevent colliding with a pedestrian.

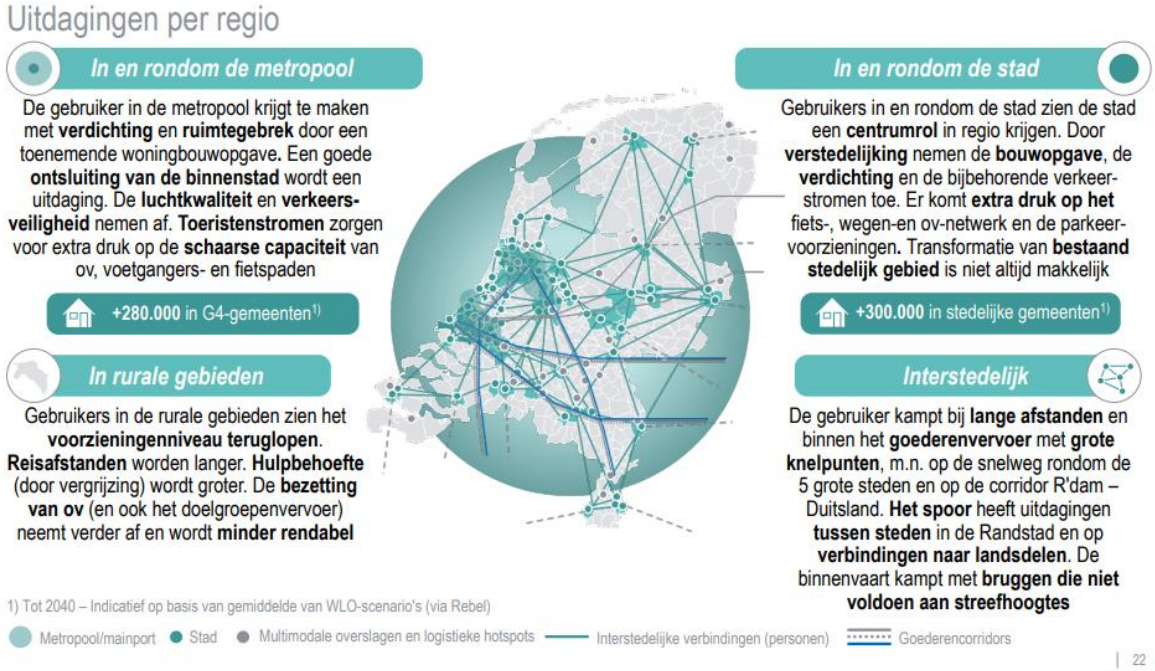
- file:///H:/My%20Documents/Studie/Relevante%20documenten%20(nader%20te%20orderen)/mobiliteitsbeeld+2019.pdf
  - 1.5 Trein

    Treingebruik in Nederland neemt toe, vooral door bevolkingsgroei en verbeterde kwaliteit treindiensten
  - 1.5.1 Gebruiksontwikkeling trein
    - Tussen 2010 en 2018 is in Nederland de in totaal met de trein gereisde afstand toegenomen met 14%.
    - Ook per inwoner van Nederland nam het treingebruik toe, met 9,9% van 1.030 km naar 1.132 km per inwoner per jaar.
    - De totale groei (in gereisde afstand) tussen 2017 en 2018 is 2,4% voor NS en 2,2% voor alle vervoerders samen.
  - 1.5.2 Verklarende factoren gebruiksontwikkeling trein
    - Een factor die veel bijdraagt aan de groei van het treingebruik, is kwaliteitsverbetering van de treindiensten (treinfrequenties, netwerkuitbreiding, aansluitingen tussen treinen: 'Level of service'). Op basis van alléén de veranderde kwaliteit van de treindiensten zou de gereisde afstand zijn toegenomen met 5,0%.
    - Hiernaast hebben de ontwikkeling van de bevolking, de toename van het treingebruik van en naar Schiphol en de ontwikkeling van het aantal banen een grote invloed op het treingebruik gehad (goed voor een toename van de gereisde afstand van respectievelijk 5,0%, 3,0% en 1,7%).
      Schiphol komt hier specifiek naar voren, omdat het gebruik Ministerie van Infrastructuur en Waterstaat Mobiliteitsbeeld 2019 | KiM 26 van de luchtvaart door passagiers, en hiermee het gebruik van de luchthaven Schiphol, sterk is gegroeid (57% tussen 2010 en 2018). Doordat de trein een belangrijke rol speelt in het voor- en natransport van de luchthaven Schiphol, leidt meer vliegen door passagiers ook tot meer treingebruik.
    - De ontwikkeling van het reëel inkomen en het gebruik van de ov-studentenkaart leveren een kleine bijdrage aan het toegenomen treingebruik (goed voor een toename van respectievelijk 0,8% en 0,5% in de gereisde afstand).
      Het gebruik van de ov-studentenkaart groeit doordat de deelname aan het hoger onderwijs in deze periode verder toenam (OCW, 2019) en doordat sinds 1 januari 2017 ook studenten onder de 18 jaar die een beroepsopleidende leerweg volgen, recht hebben op de ov-studentenkaart.

- De gestegen treintarieven, gecorrigeerd voor inflatie, hebben een neerwaarts effect op het treingebruik (goed voor een afname van de gereisde afstand met -1,5%).
- Hiernaast hebben het toegenomen autobezit en de dalende brandstofkosten geleid tot een afname van de per trein gereisde afstand (met respectievelijk -0,2% en -0,7%).
- Ontwikkelingen op het gebied van de congestie hebben over de periode 2010-2018 geen effect op het treingebruik gehad.
- Het saldo van alle voorgaande factoren leidt nog niet tot de uiteindelijke ontwikkeling van het treingebruik over de

1.1.1 Demographic

- https://www.ns.nl/binaries/_ht_1582797451971/content/assets/ns-nl/over-ns/nederland-duurzaam-bereikbaar.pdf
  - De steden worden steeds drukker, veel regio's kampen met krimp. De wijze waarop we ons voortbewegen, is daarbij cruciaal.
  - Mobiliteit groeit de komende decennia tot 2040 nog met maximaal 40%.
- https://magazines.rijksoverheid.nl/ienw/ienw-specials/2019/07/pijler-1-focus-op-de-kracht-van-het-ov
- https://mobiliteitsalliantie.nl/wp-content/uploads/2019/06/Trends-en-ontwikkelingen.pdf
  Verplaatsingen, stromingen, etc., drivers voor mobiliteitsvraag/aanbod
  - Tot 2030 zet verstedelijking door, in de G4 groeit de bevolking naar verwachting met ~11% tot 2030 (CBS) wat leidt tot kortere afstand per verplaatsing– Het voorzieningenniveau in rurale gebieden zal teruglopen, wat leidt tot langere afstand per verplaatsing
  - Tot 2030 kan door flexwerken het aantal autokilometers in de spits verder dalen – Tussen 2000 en 2016 is door Het Nieuwe Werken het aantal autokilometers in de spits al met ~14% gedaald, treingebruik in de spits is met ~9% verminderd (KiM)
  - Tot 2030 groeit de bevolking verder, waarbij het aantal ouderen groter wordt – Ouderen (65+) maken gemiddeld 30% minder verplaatsingen t.o.v. van 20 – 65 jarigen, eisen aan de toegankelijkheid van mobiliteit zullen daardoor veranderen (CBS)



- https://mobiliteit.gelderland.nl/Trends/480455.aspx?t=Verstedelijking+zet+door
  Verstedelijking zet door

- Jongeren en migranten trekken naar de stad en ook steeds meer gezinnen, dat betekent dat de vergrijzing in de stad relatief gezien afneemt. Er zijn ook steeds meer eenpersoonshuishoudens waardoor het ruimtebeslag per inwoner groeit.
- Er zal een 24 uurs economie ontstaan zonder vaste spits. In de stad komt alles samen, de problemen en de kansen.
- De mobiliteit in de stad neemt ook toe, niet alleen door de groei van de inwoners, maar ook doordat mensen in hun vrije tijd er steeds meer opuit trekken. Voor de regio eromheen betekent dit meer recreatieve mobiliteit en doordeweeks een rustig en groen buitengebied.
- Enerzijds betekent dit dat de binnenstedelijke bereikbaarheid steeds belangrijker wordt, anderzijds missen sommige steden kritische massa waardoor de verbindingen tussen steden erg belangrijk zijn voor de agglomeratiekracht.
- Vervoer zal door deze mensenmassa die kwaliteit eist ook snel schoner en stiller worden.

- https://mobiliteit.gelderland.nl/Trends/480451.aspx?t=Mass+transit+neemt+toe
  - Het aantal reizigerskilometers per trein nam toe van 14,5 miljard in 2004 tot 18,2 miljard in 2014, een toename van 25 procent. Dit betekent een gemiddelde jaarlijkse groei van bijna 2,3 procent.
  - De omvang van het treingebruik in 2020 ligt naar schatting van het KiM tussen de 19,9 en 21,2 miljard reizigerskilometers. Dit komt neer op een gemiddelde groei van 1,6 respectievelijk 2,7 procent per jaar vanaf 2011.
    - https://nieuws.ns.nl/ns-jaarcijfers-2019--treinreiziger-gaat-er-in-5-jaar-fors-op-vooruit/
    - https://www.ovpro.nl/special/2019/08/16/ns-vanaf-2027-te-weinig-spoorcapaciteit/?gdpr=accept
    - https://www.spoorpro.nl/spoorbouw/2018/10/31/kim-voorspelt-14-procent-groei-treingebruik-tot-2023/
    - https://www.treinreiziger.nl/ns-langere-perrons-nodig/
  - Het treingebruik neemt tot 2030 fors toe, met een kwart tot bijna een derde. Dit komt vooral door verbeteringen in het treinenaanbod.
  - Een strenger klimaatbeleid (Parijs) kan de vraag naar mass transit doen toenemen.
- https://mobiliteit.gelderland.nl/Trends/480445.aspx?t=Gezondheid+en+milieu+worden+nog+belangrijker%09
  - Gezondheid en milieu zijn onderwerpen de kwaliteit van leven beinvloeden. Schone lucht en voldoende beweging zijn voorbeelden van factoren die de levensverwachting verhogen. De huidige levensverwachting van Nederlandse mannen is 79 jaar. Vrouwen worden gemiddeld 83 jaar. De levensverwachting steeg de laatste 10 jaar sterk, met meer dan 3 jaar in NL.
  - Hugo van der Steenhoven: Gezond eten, leven en fit ouder worden worden steeds belangrijker
  - Hoewel de levensverwachting blijft stijgen, neemt het aantal mensen met een ziekte toe. Deze stijging betekent echter niet dat de kwaliteit van leven evenredig daalt. De vraag is wel in hoeverre de mobiliteitsbehoefte hierdoor verandert.
- https://mobiliteit.gelderland.nl/Trends/480443.aspx?t=Meer+fietsgebruik
  - WLO 2015, cahier Mobiliteit, pagina 45): Tenslotte is gekeken naar de bereikbaarheid van banen binnen acceptabele reistijd per langzaam vervoer. Deze neemt in beide scenario´s toe door een sterkere stedelijke concentratie (plus 12 procent richting 2050) en vooral door de rol van de elektrische fiets. Deze maakt het reizen per fiets sneller, waardoor er binnen dezelfde tijd meer banen kunnen worden bereikt (+ 30-38%).
- https://mobiliteit.gelderland.nl/Trends/480437.aspx?t=Meer+vliegen+tussen+metropolen
  Meer vliegen
  - Het aantal passagiersbewegingen op de regionale luchthavens groeide in 2014 met bijna 9 procent naar 6 miljoen. Het aandeel van de regionale luchthavens ten opzichte van het totaal aantal passagiersbewegingen in Nederland is in de laatste tien jaar verdubbeld naar zo'n 10 procent.
  - Deze trend zet zich door omdat……

    - Er steeds meer internationale verbindingen zijn tussen grote metropoolregio's.
    - Luchtvaart nog steeds relatief goedkoop is voor tijdkritische goederen.
    - Er steeds meer zuinige vliegtuigen worden opgeleverd (Boeing 777 en Airbus)
    - Het verdienmodel van luchtvaartmaatschappijen en luchthavens verschuift van het vervoer zelf naar het aanbieden van aanvullende producten en diensten.
  - WLO 2015: In scenario Laag neemt de vervoersvraag vanaf Schiphol toe naar ruim 110 miljoen passagiers in 2050 (zie figuur 4.10). In scenario Hoog groeit de vervoersvraag op Schiphol naar een kleine 170 miljoen passagiers in 2050: een gemiddelde jaarlijkse groei van 3 procent.
- https://mobiliteit.gelderland.nl/Trends/480435.aspx?t=Meer+mobiliteitsdiensten
  Meer mobiliteitsdiensten
  - De mobiliteitsdiensten spelen in op de behoefte van reizigers en bedrijven om snel, flexibel en gemakkelijk vervoer te krijgen.
  - Deze trend zet zich door omdat de mogelijkheden steeds groter worden door:
    - Groei data reisgedrag
    - Groei data beschikbare vervoerscapaciteit/-mogelijkheden
    - gebruikers steeds meer wennen aan voorgestelde diensten, denk aan Amazon die op basis van eerder zoekgedrag producten aanbiedt.
    - de verschuiving in de verdienmodellen van autofabrikanten een belangrijke driver vormt, OV-bedrijven, leasemaatschappijen: van vervoermiddel naar extra diensten er omheen. Noodzakelijk door druk op efficiency en behouden marktaandeel.
    - een dienstverlener zelf geen vervoermiddel hoeft te bezitten om toch diensten aan te bieden: denk aan Uber, AirBnB die zelf niets bezitten.
  -

1.1.2 Economic

Mobility

- https://www.ns.nl/binaries/_ht_1582797451971/content/assets/ns-nl/over-ns/nederland-duurzaam-bereikbaar.pdf
  - De zelfrijdende auto kan bijvoorbeeld invloed hebben op de gebruikerskosten van verschillende vormen van mobiliteit, waaronder de trein.
- https://magazines.rijksoverheid.nl/ienw/ienw-specials/2019/07/pijler-3-veilig-en-efficient-ov
  - Veel van de huidige middelen ten behoeve van OV-investeringen zijn al belegd en extra middelen zijn beperkt, mede doordat de kosten voor beheer, onderhoud en vernieuwing zullen toenemen.
- https://mobiliteitsalliantie.nl/wp-content/uploads/2019/06/Trends-en-ontwikkelingen.pdf
  - Tot 2030 groeit de economie naar verwachting met 1-2% (WLO) – Op kortere temijn kunnen Brexit en protectionisme grote impact hebben op invulling van de vraag
- https://www.cbs.nl/nl-nl/nieuws/2019/36/prijzen-openbaar-vervoer-stijgen-sterker-dan-autokosten
  - De prijzen van het openbaar vervoer zijn na verloop van tien jaar sterker gestegen dan de autokosten. Vergeleken met 2009 lagen de prijzen van het openbaar vervoer in juli 2019 bijna 30 procent hoger. Kosten voor het rijden in de eigen auto lagen gemiddeld een kwart hoger.
  - Het beeld van de prijsontwikkelingen over langere termijn wordt beïnvloed door de gekozen periode waarover gemeten wordt en het aanvangsjaar van de periode. Sinds 2009 nam de prijs voor reizen met het openbaar vervoer geleidelijk en stapsgewijs toe. De autokosten ontwikkelden zich grilliger. In de periode 2009 tot 2015 stegen de autokosten sterker dan de tarieven van het openbaar vervoer. Tussen 2015 en 2019 lag de ontwikkeling van de autokosten juist meestal onder die van de openbaarvervoerprijzen.
  - De prijzen voor het reizen met de trein, tram en metro lagen in juli 2019 bijna een kwart hoger dan in 2009. Reizen met de bus of taxi werd in diezelfde periode bijna 40 procent duurder. Vooral het laatste jaar gingen de prijzen van het openbaar vervoer omhoog.

- Op jaarbasis stegen de prijzen in juli 2019 voor het reizen met het openbaar vervoer met 5,5 procent. Het reizen per spoor steeg in dezelfde periode met 4,6 procent in prijs. De prijsstijging in juli 2019 was de één na sterkste sinds halverwege 2005. In januari van dit jaar werd het lage btw-tarief, dat geldt voor openbaar vervoer, verhoogd van 6 naar 9 procent. Treinkaartjes en abonnementen waren in juli 4,4 procent duurder dan vorig jaar. Wie met de tram of metro reed was 5,7 procent meer kwijt.
  Ook openbaar vervoer over de weg werd duurder. In juli was de prijsstijging voor het reizen per bus 7,7 procent. Vervoer per taxi werd 6,7 procent duurder.
- De prijsstijging van het personenvervoer over het spoor en over de weg in Nederland was in juli 2019 de grootste van alle landen in Europa.
- In Nederland gaat er een groter deel van het besteedbaar inkomen naar het vervoer over het spoor, terwijl gemiddeld in Europa een iets groter deel gaat naar het vervoer over de weg.

1.1.3 Political

- https://www.ns.nl/binaries/_ht_1582797451971/content/assets/ns-nl/over-ns/nederland-duurzaam-bereikbaar.pdf
  - Zo zijn in het ontwerp-Klimaatakkoord afspraken gemaakt voor een reductie van uitstoot van broeikasgassen met 49% in 2030.
- MA
  - Gemeenten voeren meer maatregelen in voor autoluwe binnensteden (deze ambitie wordt in de plannen van elke G4-gemeente uitgesproken) – Dit stimuleert naar verwachting het aandeel lopen, fietsen, ov-gebruik en multimodale verplaatsingen
  - De EU doelstelling voor maximale uitstoot van een personenauto in 2030 is 70g CO2/km, momenteel is dit nog 120g CO2/km, volgens de EU – Ook de fietstreincombinatie in de deur-tot-deurreis zal door aanbod van deelfietsen verder groeien

1.1.4 Environmental

- https://www.ns.nl/binaries/_ht_1582797451971/content/assets/ns-nl/over-ns/nederland-duurzaam-bereikbaar.pdf
  - Zo zien we ook de tendens om voor reizen in Europa korter dan 700 kilometer de veel duurzamere trein te nemen in plaats van het vliegtuig.
- https://magazines.rijksoverheid.nl/ienw/ienw-specials/2019/07/pijler-3-veilig-en-efficient-ov
  - OV is al erg duurzaam, transitie naar emissievrij
  - Inrichten openbare ruimte
- Mobiliteitsalliantie
  - Door bewustwording over duurzaamheid en afspraken in klimaatakkoorden neemt tot 2030 het transport van fossiele brandstoffen naar verwachting af (TNO) – Binnen het personenvervoer neemt aandeel duurzame opties naar verwachting toe (o.a. ov)
- https://mobiliteit.gelderland.nl/Trends/480445.aspx?t=Gezondheid+en+milieu+worden+nog+belangrijker%09
  - De maatschappelijke kosten (milieueffecten) van het verkeer, daalden tussen 2004 en 2014 sterk, met 25 procent. Vooral de kosten van luchtvervuiling (NOx, PM10, SO2) daalden, in lijn met de dalende emissietrends.
  - Menno Menist: Iedereen wil slimme, schone en duurzame mobiliteit;
  - Geert Kloppenburg: Stel doelen als Unilever: 50% meer omzet en 50% minder milieudruk;
  - Ewald Breunesse: Er is geen rechte weg naar duurzaam. De aanpak van CO2-emissies in de EU is wel een stok achter de deur.
  - Deze trend zet zich door. De recente klimaatafspraken in Parijs hebben de ambitie verhoogd. Het kabinet houdt vast aan de afspraak dat de CO2-uitstoot in 2030 met 40 % en in 2050 met 80-95% moet zijn teruggedrongen op Europees niveau.

1.1.5 Social

- https://www.ns.nl/binaries/_ht_1582797451971/content/assets/ns-nl/over-ns/nederland-duurzaam-bereikbaar.pdf
  - We stellen andere eisen aan de beschikbaarheid van vervoermiddelen. Het kunnen gebruiken en delen van auto's, scooters, fietsen en zelfs steppen is belangrijker dan er eentje bezitten.
  - Reizigers verwachten steeds meer een gepersonaliseerde deur-tot-deurreis.
- https://magazines.rijksoverheid.nl/ienw/ienw-specials/2019/07/pijler-2-drempelloos-van-deur-tot-deur
  - Deur tot deur reis wordt belangrijker
  - Knooppunten als sociale hub
- Mobiliteitsalliantie
  - Richting 2030 wordt toegang tot producten en diensten belangrijker dan eigendom – Private lease contracten stegen +45% in 2018 naar 150.000 (VNA), Swapfiets ('leasefiets') groeide in één jaar naar 50.000 klanten en deelconcepten winnen populariteit
  - Deelsystemen worden populairder richting 2030 – Het aantal deelauto's is gestegen van 2.500 naar >40.000 (+63% p/j 2012-2018, CROW) – Gebruik van deelfiets stijgt ook; de ov-fiets is meer dan 4 miljoen keer verhuurd in 2018 (+10% p.j. 2009-2018, NS)
  - Autobezit groeit naar verwachting richting 2030 (+6-18% t.o.v. 2010, WLO) – Jongeren (18 – 29 jaar) reizen minder met de auto (15-30% minder kilometer t.o.v. 1995), het autogebruik (en bezit) groeit als ze ouder worden (KiM)
- https://magazines.rijksoverheid.nl/ienw/ienw-specials/2019/07/pijler-3-veilig-en-efficient-ov
  - Veiligheid en leefbaarheid
- https://mobiliteit.gelderland.nl/Trends/480447.aspx?t=Grensvervaging+publiek+en+privaat+vervoer
  - Het parkeren van auto's en de zorg over het onderhoud en diefstal doet de voorkeur verschuiven van bezit naar gebruik. Fleetowners zullen in dit gat stappen en deelvoertuigen gaan aanbieden. Hoewel op dit moment de trend vooral op het delen van de eigen auto ligt. Daarmee wordt steeds vager waar het openbaar vervoer ophoudt en het privé vervoer begint.
  - Mass transit zal blijven bestaan en zelfs groeien in de steden en op drukke verbindingen.
  - Van 2014 naar 2015 vond een groei plaats van 28% in deelauto's (KPVV)
  - Je agenda en niet het bezit van een auto wordt leidend voor hoe je vervoer de dag erop verloopt (Stefan Hulman 9292)
  - Zolang we in Nederland een studentjaarkaart hebben voor het OV zal de nieuwe Uber niet in Nederland worden uitgevonden. (Carlo van de Weijer, hoofd smart mobility TUE)
  - Er ontstaan steeds meer mogelijkheden om tijdelijk toegang te krijgen tot mobiliteit anders dan door permanent eigendom. (Luca Bertollini)
  - Er ontstaat een mix van bedrijven die zich begeven in publieke zaken en omgekeerd. Iedereen met een voertuig dat hij tegen betaling uitleent of deelt is een klein bedrijfje en tegelijk zijn OV bedrijven in vastgoedontwikkeling gestapt rond hun OV knooppunten.
  - Ook zullen goederenvervoer en personenvervoer meer gaan mixen. Je kunt makkelijk een pakketje meenemen als het toch op je route ligt.
  - Daar ontstaat wel de vraag wie er verantwoordelijk is voor de veiligheid van de semi openbare mobiliteitsconcepten, voor de datastroom met privacygevoelige gegevens, voor de mensen die hier geen gebruik van kunnen maken etc.
- https://mobiliteit.gelderland.nl/Trends/480443.aspx?t=Meer+fietsgebruik
  Meer fietsgebruik
  - De ontwikkeling van meer gebruik van de fiets gaat over de toename van het gebruik van de fiets ten opzichte van nu (2016). Het gaat dan zowel om de traditionele fiets als om de elektrische fiets.

  - De toename van het gebruik uit zich in de aantallen fietsers, in de toename in het aantal afgelegde kilometers, maar bijvoorbeeld ook in het aantal fietsen dat mensen thuis hebben staan of kunnen huren/lenen.
  - RTL-Nieuws, 15 januari 2016: Treinreiziger pakt vaker dan ooit de OV-fiets
  - Deze trend zet zich door omdat……
    - fietsen past in fijnmazige steden
    - de kosten beperkt blijven ten opzichte van ander vervoer
    - de voordelen van auto ten opzichte van fiets vervagen (snelheid, flexibiliteit, actieradius)
    - gezondheid een driver voor fietsen is.
    - de actieradius enorm toeneemt door de opkomst van elektrische fietsen.
    - fietsen met steeds meer technische hulpmiddelen worden uitgerust voor vergroting van de veiligheid en reisgemak.
    - de OV-fiets steeds verder wordt doorontwikkeld in nieuwe deelconcepten op plaatsen waar veel mensen bij elkaar komen.
- https://www.capgemini.com/nl-nl/wp-content/uploads/sites/7/2018/04/trends-in-mobility-2018-report.pdf
  - Gedrag
    De mens is een belangrijke factor in mobiliteit. De vraag is hoe we onszelf kunnen beinvloeden om de juiste keuzes te maken om zo de congestive terug te dringen.
  - Mobility as a service
    Het bezit van een auto is niet langer een statussymbool. Steeds meer diensten zijn erop gericht om mobiliteit als een dienst op afroep aan te bieden. Dit bidet kansen voor een efficiëntere indeling van voertuigen op de weg, het water en in de lucht.
-

1.1.6 Technology

- https://www.ns.nl/binaries/_ht_1582797451971/content/assets/ns-nl/over-ns/nederland-duurzaam-bereikbaar.pdf
  - Elektrisch reizen wint terrein. Technische innovaties maken reizen efficiënter en veiliger.
  - We zien nieuwe aanbieders en vormen van mobiliteit.
  - Alle vormen van mobiliteit zijn straks zowel fysiek als digitaal met elkaar verbonden. De autonome, zelfrijdende auto komt eraan.
- https://magazines.rijksoverheid.nl/ienw/ienw-specials/2019/07/pijler-2-drempelloos-van-deur-tot-deur
  - Naadloos aansluiten van OV/vraag gestuurde mobiliteit
  - Data delen
- MA
  - Door de geplande (verdere) introductie van ADAS-systemen en meer comfort in het ov kunnen gebruikers tijdens hun reis werken of ontspannen, wat leidt tot meer flexibiliteit en gemak en een hogere reistijdwaardering
  - In gebieden waar het (in de toekomst) niet rendabel is om vaste ov-lijnen te rijden worden in toenemende mate vraaggestuurde ov-systemen geïntroduceerd (bijv. Flex in Noord-Brabant en Arnhem-Nijmegen)
  - E-bike/speedpedelec verkoop stijgt sterk – In 2018 40% van totale verkoop fietsen een ebike, wat een stijging van 33% naar ~410.000 is (RAI) – Deze zijn een alternatief voor auto en ov voor afstanden tot 15km, maar ook langer (~25km) voor bepaalde doeleinden
  - Ontwikkeling van autonome (vracht)auto's en ov gaat snel richting 2030 – Verwacht wordt dat in 2030 5-12% van de wereldwijd verkochte auto's vol-autonoom zijn (Roland Berger) – Dit leidt mogelijk op de lange termijn tot meer veiligheid en hoger comfort1)
  - Elektrificering van voertuigen zal door technologische vooruitgang, toenemend aanbod en overheidsbeleid het komende decennium doorzetten

  - Voertuigen en infrastructuur worden naar verwachting steeds meer connected waardoor beschikbare ruimte steeds efficiënter kan worden benut (qua weg-, vervoers-, en laadcapaciteit) – Informatie wordt accurater en de reis betrouwbaarder
  - De doorontwikkeling van Mobility as a Service zal het reisgemak ingrijpend verbeteren en het mobiliteitsaanbod veranderen en optimaliseren – de afgelopen jaren zijn al veel nieuwe mobiliteitsdiensten opgekomen (ViaVan, Felyx, Tranzer, enz.)
  - Steps, hoverboards en andere vormen van micro-mobiliteit nemen toe en zullen mobiliteit naar verwachting toegankelijker maken voor met name korte afstanden voor personen en bezorgdiensten
- https://mobiliteit.gelderland.nl/Trends/480453.aspx?t=Snelle+technologische+ontwikkelingen+ Snelle technologische ontwikkelingen
  - " De technologische ontwikkeling zal sneller gaan dan de mens. De mens bereikt een plafond als het gaat om technologische ontwikkeling (Marieke Martens)"
  - "Technologische ontwikkelingen groeien exponentieel. De mens daarentegen is een constante factor die iets meer dan een uur per dag mobiel wil zijn (Carlo van de Weijer)"
  - Internet of Things; meer mensen en ook meer dingen zijn verbonden met internet
  - 'Living technologies' Convergerende sleuteltechnologieën leiden tot toenemende technologische maakbaarheid
  - 'The Zero Marginial Cost Society' Exponentiële technologie tegen steeds lagere kosten
- https://mobiliteit.gelderland.nl/Trends/480441.aspx?t=Meer+diversiteit+in+voertuigen
  - De technologische ontwikkeling, maatschappelijke trends en de schaarse ruimte in steeds drukker wordende steden leiden tot de ontwikkeling van nieuwe typen voertuigen Fleetowners zullen een diversiteit aan voertuigen aanbieden. Voor elke rit is maatwerk beschikbaar.
  - Tot nu toe is dit alleen voor de early adopter. Bij de grote massa groeit het vertrouwen in nieuwe voertuigen en concepten langzaam.
  - Maar er zijn al: zelfrijdende voertuigen op laag niveau, (e-)scooters, (e-)bikes, speedpedelecs, hooverboards, witkar, greenwheels, smartauto's, stepjes, etc.
  - De privé auto's zullen luxer worden en de bestuurder meer ondersteunen. Dit speelt in op de veiligheid waar steeds hogere eisen aan gesteld worden,
  - maar ook op de funfactor. Dat zien we ook in andere ontwikkelingen zoals de hooverboard en de speedpedelec. Mensen vinden dergelijke voertuigen gewoon kicken. Ook de fiets zal naast de snelheid slimmer worden waardoor het zelf de route kan bepalen en steeds uitzend waar hij is en wat hij gaat doen naar andere weggebruikers. Ook zullen veilige fietsen ontwikkeld worden voor ouderen.
  - In de stad komt de nadruk te liggen op kleine lichtgewicht voertuigen en de fiets.
- https://mobiliteit.gelderland.nl/Trends/480439.aspx?t=Informatiesamenleving
  - Dit brengt nieuwe vraagstukken met zich mee, die betrekking hebben op veiligheid, ethiek en privacy.
  - Deze trend zet zich door omdat de technologie gekoppeld aan de informatie samenleving hard op weg is de nieuwe normaal te worden. Dit zie je terug in de penetratiegraad van de nieuwe technologieën.
  - Schattingen over het totale aantal apparaten dat in 2020 verbonden zal zijn met het internet lopen uiteen van 30 miljard tot 50 of zelfs 100 miljard. Volgens een rapport van de Britse regering zijn er in 2015 al 14 miljard apparaten met het internet verbonden.
  - Er hangen dan ook donderwolken aan de horizon zoals de sterk groeiende werkdruk; we krijgen namelijk dagelijks een verdubbeling van de hoeveelheid informatie te verstouwen. Robots komen ons werk massaal overnemen. En op sociaal gebied zien we buitensporig groeiende kloven in de samenleving tussen digitaal vaardigen en digibeten.
- https://mobiliteit.gelderland.nl/Trends/480427.aspx?t=Opkomst+andere+brandstoffen
  - De ontwikkeling van de opkomst van duurzame brandstoffen gaat over de verschuiving in het gebruik van fossiele brandstoffen (benzine, diesel, kerosine) naar andere, schone en hernieuwbare brandstoffen. Denk hierbij bijvoorbeeld aan elektriciteit, waterstof, biogas.

- Bij de daling van de CO2-uitstoot per gereden kilometer spelen, naast Europese CO2-normen voor personenauto's en bestelauto's, ook het Nederlandse fiscale beleid voor zuinige auto's en de olieprijs een rol.
- Deze trend zet zich door omdat……
  - er druk is bij overheden en andere partijen om de klimaatafspraken van Parijs (november 2015) na te komen. Extra inzet via SER-energieakkoord en Gelders Energieakkoord, in het uiterste geval is er bereidheid tot regulering.
  - er steeds beter te verdienen valt aan duurzaam vervoer
  - duurzame voertuigen steeds goedkoper worden om aan te schaffen en de actieradius van accu's toeneemt
  - de laadinfrastructuur steeds verder wordt uitgebreid en zich door ontwikkelt (snelheid, capaciteit)

- https://www.capgemini.com/nl-nl/wp-content/uploads/sites/7/2018/04/trends-in-mobility-2018-report.pdf
  - Voertuigen
    In de afgelopen Jaren zijn er meerdere technologische ontwikkelingen geweest met betrekking tot het soort voertuigen op onze vaar-, lucht-, spoor- en autowegen. Met name de autonome en verbonden voertuigen en drones hebben hun intrede gemaakt.
  - Infrastructuur
    Onze infrastructuur is constant in ontwikkeling en wordt alsmaar slimmer. Door middel van bijvoorbeeld sensoren is gebruik, monitoring en onderhoud beter in te plannen.

1.2 MATERIALS

- https://www.nwo-i.nl/wp-content/uploads/2016/03/dutch-materials-challenges-finale-version-1-12-2015_factual-corrv160310-325740.pdf
  - The European Research Programme 'Horizon 2020' explicitly recognises the importance of Materials Science by positioning it as one of six Key Enabling Technologies (KET's) for several societal challenge-oriented programs, including:
    - Health, demographic change and well-being (with a focus on biomaterials and soft matter research, et cetera),
    - Secure clean and efficient energy (with research on innovative technologies for energy efficiency and renewable sources of energy, et cetera),
    - Smart green and integrated transport (where advanced materials are developed for transport infrastructure, environmental-friendly multifunctional composite manufacturing, materials for the aircraft and aeronautical industry, et cetera),
    - Climate action, environment, resource efficiency and raw materials (where materials are studied for recycling and reuse, the processing and structuring materials to reduce food waste, use in packaging materials, et cetera.),
    - Factories of the Future (that includes high-definition printing of multifunctional materials, industrial technologies for materials assembly, et cetera),
    - Energy-efficient buildings (with research on smart building structures; lightweight and high-strength materials, et cetera). A major new EU initiative is the establishment of Future Emerging Technology Flagships; the first one is the materials-related Graphene Flagship that was established in 2013.
  - Multidisciplinary Materials Science: bridging the engineering and innovation gaps
  - In this section we identify six strategic research directions that cover major challengesin materials research today. They build on key expertise that has been built up in the Netherlands over the past years as described in the previous section. The six strategic themes are:
    1. Designer functional metamaterials
    2. Soft and bio-inspired materials
    3. Next-generation engineering materials
    4. Materials for sustainable energy production and storage
    5. Sustainable materials

6. Thin films and coatings

The challenges described in this report typically focus on medium-term (2-5 years) and long-term (5-10 years) goals: research that is typically not carried out by industry (alone). Research on these challenges will provide a knowledge base that can lead to innovations over a period of 2 to 10 years from now.

- Microsoft file:///H:/My%20Documents/Afstuderen/Manufacturing_Ebook.pdf
  - Internet of Things
    The Internet of Things (IoT) is having a major impact on manufacturing, giving manufacturers more visibility into their operations, enabling predictive maintenance on their machines, and allowing them to provide remote support to their customers.
    Highlights
    - There will be nearly 20.8 billion devices on the IoT by 2020.
    - 41% of manufacturing organizations use sensor data frequently.
    - Wearables are being used to improve worker safety, education, and customer support.
  - B2B to B2B2C
    Brands are trying to manage growing customer expectations by taking greater control over their value chain, from R&D to delivery. This is forcing manufacturers to shift from B2B to B2B2C businesses, placing a greater emphasis on the end user's needs and experience.
    Highlights
    - Increased customer demands are forcing businesses to take greater control of their value chain.
    - Manufacturers need to be more transparent and end-customer focused.
    - 87% of global consumers consider CSR when making a purchase decision.
  - Evolving value chain
    Manufacturers are evolving their value chain to provide a stronger focus on customer experience, better support, and more transparency. Highlights
    - 64% of companies surveyed said that their ability to negotiate and collaborate with value chain partners will become more important.
    - 29% of businesses reported that personalized service through technology was already disrupting their market.
    - 59% of manufacturers already use robotics technology.
  - Greater visibility
    With better data collection and cloud-enabled analytics platforms, manufacturers have greater visibility into their businesses and operations than ever before.
    Highlights
    - 45% of organizations said that gaining access to data from different areas of the business was a top pressure driving their need for analytics.
    - 47% of global businesses feel they have insufficient access to the data they need.
    - SMAC-stack (Social, Mobile, Analytics, and Cloud) is changing the way manufacturers do business.
  - Emerging technology
    Technology has always been a driver of innovation in manufacturing and today's emerging technologies are no different. From 3D printing to nanotechnology, these cutting edge tools and techniques are changing how products are made.
    Highlights
    - 66.7% of U.S. manufacturers have deployed 3D printers in some capacity.
    - Autonomous devices are on the cusp of revolutionizing manufacturing operations.
    - Nanotechnology is enabling atomically precise manufacturing (APM).
  - Agile manufacturing
    Many manufacturers are moving towards an agile manufacturing approach to stay responsive to evolving customer demands and to meet the need for greater product customization.
    Highlights
    - Product release cycles are decreasing across many industries.

    - Many businesses are moving from larger releases to smaller, iterative updates.
    - Speed-to-market was the top motivation for manufacturers to collaborate on innovation (25%).
  - Small is the new big
    Advancements in manufacturing technology, lower cost of entry, a need for speed, and the demand for more customized products is leading to growth in smaller, more localized manufacturing.
    Highlights
    - The top reason for localizing manufacturing was to shorten supply chains (79%).
    - The artisan trend is impacting many industries.
    - A lower cost of entry is enabling a tier of small scale, low volume manufacturers.
- file:///H:/My%20Documents/Studie/Afstuderen/Relevante%20documenten%20(nader%20te%20orderen)/waste-as-a-resource-ecsip_en_8213.pdf
  - Competitiveness of the recycling industry
    In general, the process from collection of waste to secondary raw material is strongly regulated through directives. However, the markets are competitive on a global scale. Thus, scrap metals are increasingly exported, the paper industry is a global frontrunner when it comes to recycling, and materials recovered from batteries can be sold to Asia. For all the waste streams there are areas were the competitiveness of the waste stream from collection to raw materials market could still be improved including improving collection systems or processing technologies. The effectiveness of the collection and treatment systems decides their ability to produce and offer secondary raw materials to client industries at competitive prices.
  - Competitiveness in the client industries
    If secondary raw materials produced by the recycling industry can be put on the market for raw materials at competitive prices (lower than virgin raw material) in sufficient and stable quantities within the EU, secondary raw materials can have an impact on the competitiveness of its client industries. The use of secondary raw materials can reduce the EU‟s dependency on imported virgin materials in client industries from outside the EU and enhance the supply stability and security in accessibility of materials.
    - Scrap metal is currently exported outside Europe, and demand for scrap metal in Europe is dropping. Thus, an increase in the supply of scrap metal will currently not influence the competitiveness of European industries.
- https://www.theguardian.com/sustainable-business/2015/feb/23/future-of-waste-five-things-look-2025
  - Circular rethink
    - By 2025, waste disposers “won’t be burying or burning people’s rubbish as they do today”, states Gover. These companies will merge into what he terms the “reprocessing industry”, where their central role is not to dump stuff but to return “valuable resources to manufacturers”.
    - A similar rethink is required of designers and manufacturers too. The goods of today, Gover says, need to be seen as the raw materials of tomorrow. When that happens, products will begin to be made with a view to lasting longer and to being easier to repair and ultimately dismantle.
  - Turning waste into energy
    - Even if they do undergo this transformation, waste companies will still need business models that can turn a profit. One solution is turning waste into energy.
    - While most of the growth to date has been in thermal technologies, biological technologies could provide a major breakthrough.
  - Ratchet up recyclability
    - Another hurdle for manufacturers is the recyclability of materials, especially that of sophisticated plastics or other complex materials. Closing these “resource loops” is essential, he adds. “We will also need more clever technology to separate materials quickly and efficiently for recycling.”

- Convincing consumers
  - Between now and 2025, public attitudes to waste require a radical overall too.
  - Smart measuring technology which charges consumers for the food waste they produce could change public attitudes sharpish.
- Retailer responsibility
  - Responsibility for consumer-related recycling shouldn't fall entirely on consumer shoulders. Retailers that sell unrecyclable packaging should also make a change.

1.2.1 Demographic

- Origin/sourcing/procurement of materials
  - https://et2c.com/sourcing-trends-predictions-2020/
    - Ex-China sourcing
- https://www.weforum.org/agenda/2019/06/localized-micro-factories-entrepreneurs-and-consumers/
  The way products have been manufactured has evolved significantly over the past decades. Today, most are built in large factories in low-cost regions, primarily in Asia but also increasingly in eastern Europe and South America. However, there are signs that this approach has reached its limits.Not only is it getting harder to find labor in low-cost regions to build products, the growing impact in terms of local jobs, the environment and delays in product distribution around the world is becoming even more serious.
  - Several years ago, research found that more than 50% of consumers said they prefer customized purchases, and the majority of those said they'd even be willing to pay more for a customized product or service.
  - localized economy: a distributed manufacturing operation that relies on a network of smaller, more nimble and flexible factories around the world located closer to where customers are. Simply put, corporations must increasingly think globally (in terms of emerging customer needs), but build locally (in terms of executing those needs).
  - Automation is proving to be an important link between large companies and their localization strategies. It enables not only localization in manufacturing, but innovation – and at lower costs and higher efficiency.
  - Microfactories: smaller factories that utilize automation instead of relying on expensive human labor, ensuring quality and consistency in product while enabling scale through efficient output. With their lower operating costs, microfactories effectively democratize innovation by making manufacturing more readily available to entrepreneurs, inventors and makers.
    There's been much pontificating on the idea that Industry 4.0 will eliminate manufacturing jobs, but a "think global, build local" approach bucks this trend. While globally, job loss from automation will outpace job creation from automation, locally automation is a creator – not a destroyer.
  - Globalization, simply put, has run its course. Once heralded for its cost-effectiveness, a globalized approach loses all impact in a world where low-cost labor is rapidly diminishing, and consumer demand for authenticity is steadily increasing. In this changing world, a localized approach to manufacturing is imperative for companies to succeed. Intelligent automation will enable large corporations to embrace localization and build closer to their customers than previously possible. In this world, product innovation trumps cost advantages – with no player too large or too small to reap the benefits.
- https://www.sdcexec.com/sourcing-procurement/news/10358095/six-key-trends-changing-the-supply-chain-management-today
  - Globalization
    The business landscape is rapidly becoming more global. Largely due to improvements in communications, globalization is dramatically impacting the way business is managed and transacted, even on the most local levels. No area of a business is more affected by the trend to a global business environment than the supply chain. Manufacturing, distribution,

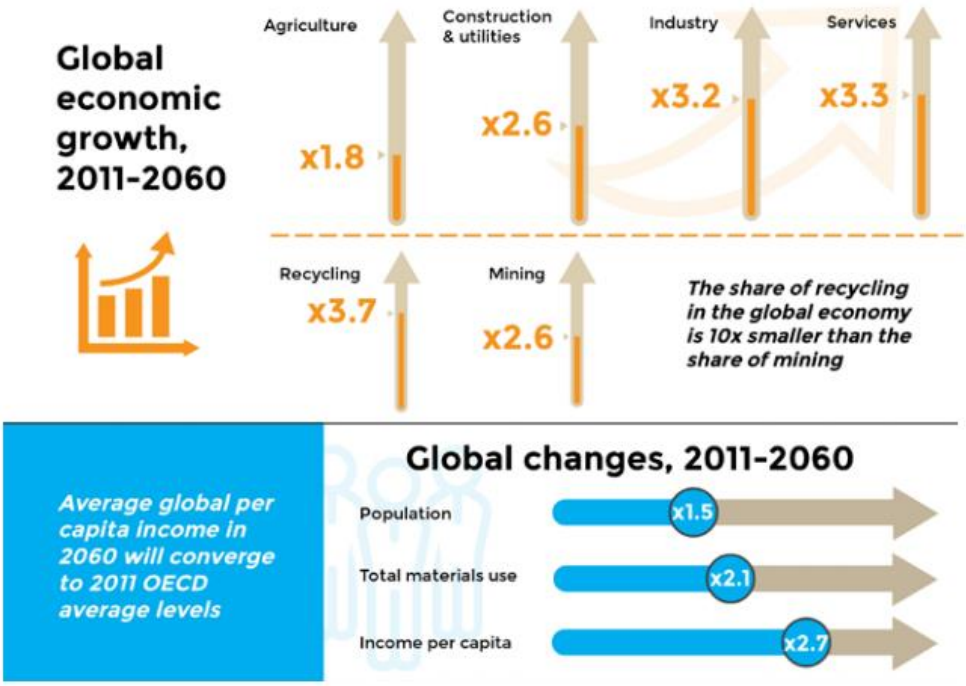
sourcing of materials, invoicing and returns have all been significantly impacted by the increased integration of a global customer and supplier base.

- https://www.industryweek.com/talent/article/21962838/5-ways-to-prepare-your-factory-for-localization
  The shift to manufacturing localization is already well underway, and it'll impact your factory at some point if it hasn't already. Prepare yourself by investing in technical efficiency, creating shared space for working with customers, and hiring locals. Design experiments to test your processes, and then recognize and reward changes that result in best practices. You'll notice the difference not only in how clients see your work, but also on the bottom line.
  - Invest in technology that allows for fast prototyping and turnaround.
    Speed is the key advantage of working with a local manufacturer. Prepare for that by enhancing the line with advanced production tools. Improve your logistics capability via internal development or partnering in order to provide fast delivery of finished product.
  - Create a shared space.
    Local customers should allow for closer cooperation. Get your customers into the factory to help with design and real-time tuning of your production facilities. You'll win a partner while making it more difficult for an overseas competitor to win business in your backyard.
  - Hire locals, regularly.
    Winning local business isn't just a matter of having the right capabilities. It's also important to have the right staff, including nearby workers with the proper domain expertise in order to limit or even eliminate relocation and recruiting costs. You'll also advertise your factory's capabilities while fostering economic goodwill.
  - Experiment and measure.
    Of course, you don't want to focus so much on local work that you forfeit overseas opportunities. Design experiments that measure the time and investment required to meet local needs versus overseas accounts. Are they more or less profitable? Why? Ideally, you'll work towards a mix that boosts overall profit as you grow to meet rising demand.
  - Create incentives and rewards to reinforce best practices.
    The recent influx of local work is sure to disrupt some factories, and yours may be among them. Don't fret if that proves to be the case. Instead, document the changes local clients demand in a search for best practices. Note what you find, and then authorize incentive pay and modest rewards (e.g., a lunch gift card, a random day off, etc.) to reinforce profitable outcomes as your factory takes on more nearby clients.
- https://hbr.org/2006/04/localization-the-revolution-in-consumer-markets
  - We're in the early stages of a quiet revolution in consumer markets. But the era of standardization is ending. When it comes to consumer markets, one size no longer fits all. They're moving from standardization to localization. Combining sophisticated data analysis with innovative organizational structures, they're gaining the efficiencies of centralized management without losing the responsiveness of local authority.
  - Standardized offerings discourage experimentation and are easy for competitors to copy. Customization encourages local experimentation and is difficult for competitors to track, let alone replicate.
  - Customers are becoming more diverse, according to studies by geodemographers, people who study the population characteristics of specific geographic areas. Standardization can do the most strategic damage by forcing products and practices into molds. The resulting homogenization of business tends to undermine innovation, all the way up the supply chain.
  - Technological advances are providing retailers and their suppliers with deep insight into local preferences and buying behaviors.
  - Thinking in Clusters: successful localization hinges on getting the balance right. Striking the right balance means understanding which elements of a business should be considered for localization, how costly they are to customize, and how much impact they will have from one store to another.

- Diversity in the Product Line: Consumer goods companies will need to introduce more variations into their lines, collaborating closely with retailers to put the right products in the right places at the right times with the right pricing and promotion programs.

1.2.2 Economic

- Economic growth
  - https://www.oecd.org/environment/waste/highlights-global-material-resources-outlook-to-2060.pdf



- Costs
  - Recycling costs
  - Waste disposal costs
    - Afvalmanager NS Remco de Wilde
      TARIEVEN VOOR VERBRANDING
      De afgelopen jaren zijn de tarieven voor verbranding langzaam maar zeker gestegen. Hiervoorzijn twee oorzaken aan te wijzen.
      1. Doordat de verwerkers enorme hoeveelheden afval importeren zorgen ze er voor dat de capaciteit eigenlijk altijd te krap is voor het stijgende aanbod (zeker door de economische groei).
      2. Vanaf 2015 is de afvalstoffenbelasting ook van toepassing op het verbranden van afval.
      Op een gemiddeld tarief (voor belasting) van ca 120 euro/Ton) geeft dit een kosten verhoging van > 25% in 5 jaar. Vanaf januari moet ook over al het afval dat uit het buitenland komt de 32,63 euro per Ton aan belasting worden betaald. Dit heeft enorme gevolgen voor de langjarige contracten die de verwerkers hebben afgesloten met partijen uit de UK, Ierland, Italie en ga zo maar door. Al deze contracten kunnen nu per direct door beide partijen ontbonden worden en of het nu nog rendabel is om tegen de gestegen kosten afval naar NL te transporteren is nog maar de vraag.
      Een effect zou kunnen zijn dat een groot deel van de 25% totale input binnen korte tijd gaat wegvallen. Als daar geen alternatief (BV Oost europa) ontstaat een situatie waarbij de verwerkers vragende partij gaan worden en dus gedwongen zijn om lager in te kopen. Een dergelijke ontwikkeling zal pas merkbaar worden als de eerste gemeentelijke aanbestedingen gaan lopen.
      Kortom, het is zeer lastig om nu te voorspellen wat de markt gaat doen. Wat we wel

met grote zekerheid kunnen stellen is dat de overheid steeds meer zal sturen door de belasting te verhogen om zo de recycling industrie te stimuleren.
Op dit moment liggen de marktprijzen voor verbranding van restafval tussen de 120 tot 150 euro per Ton (incl belasting) en volledig afhankelijk van volume en contract.
AFVALSTOFFEN BELASTING
Hieronder een overzicht van hoe de afvalstoffenbelasting zich de afgelopen jaren heeft ontwikkeld. Belangrijk om te vermelden is dat tot 2015 alleen het storten van afval is belast. Vanaf 2015 is het verbranden hieraan gelijkgesteld. Dit jaar is de verhoging zeer beperkt geweest maar dat heeft te maken met een andere wijziging. Vanaf januari 2020 is namelijk ook al het afval dat vanuit het buitenland afkomstig is belast. Ca 25% van al het afval wat in Nederland verbrand wordt is import. De huidige regering heeft wel aangegeven dat deze belasting heffing verder zal stijgen omdat NL binnen europa een laag belasting tarief hanteert en omdat dit een middel is om de recycling industrie te ondersteunen. Maar uiteindelijk blijft dit natuurlijk politiek n dus lastig om een lange termijn verwachting aan te koppelen. Een gewenst tarief dat de overheid in 2018 heeft genoemd is om richting de 100 euro per Ton aan belasting te gaan heffen.

Afvalstoffenbelasting

Met ingang van 1 april 2014:

Jaar	Tarief
2014	€ 17,00 per 1.000 kg
2015	€ 13,00 per 1.000 kg
2016	€ 13,07 per 1.000 kg
2017	€ 13,11 per 1.000 kg
2018	€ 13,21 per 1.000 kg
2019	€ 32,12 per 1.000 kg
2020	€ 32,63 per 1.000 kg

- Market trends & characteristics
  - https://et2c.com/sourcing-trends-predictions-2020/
    - Radical supply chain transparency
    - New competitiors
      Suppliers competing in sales markets with cheaper substitute products via Amazon and other platforms, effectively cannibalizing capacity and competing for the same consumers. Also, domestic sales markets taking up capacity again.
  - https://www.sdcexec.com/sourcing-procurement/news/10358095/six-key-trends-changing-the-supply-chain-management-today
    - Demand Planning Begins at the End of the Cycle
      More companies have moved away from focusing efforts on plant-level production planning and are adopting more of a demand-driven focus of trying to influence and manage demand more efficiently. Rationalizing what your company is best at selling, making and delivering, and aligning the sales force with that mindset, is critical to adopting a demand-driven model.
    - Shortened and More Complex Product Life Cycles
      Today many companies are under pressure to develop innovative products and bring them to market more rapidly while minimizing cannibalization of existing products, which are still in high demand. In order to meet the needs of both customers and consumers, companies need more efficient product lifecycle management processes. This includes heavy emphasis on managing new product introduction, product

discontinuation, design for manufacturability and leveraging across their entire product and infrastructure characteristics.

- Outsourcing
  As many companies step back and examine their core competencies some realize that outsourcing parts or all of a supply chain can be advantageous. With marketplace improvements around (1) information mediums and systems (2) cost and quality of global manufacturing and distribution and (3) product design capabilities companies are gaining additional synergies by outsourcing all or parts of their supply chain.
- Collaboration Between Stakeholders in the Extended Supply Chain
  As supply chains continue to develop and mature there has been a move toward more intense collaboration between customers and suppliers. The level of collaboration goes beyond linking information systems to fully integrating business processes and organization structures across companies that comprise the full value chain. The ultimate goal of collaboration is to increase visibility throughout the value chain in an effort to make better management decisions and to ultimately decrease value chain costs.

- https://www.zycus.com/blog/procurement-technology/7-procurement-trends-2019.html
  As procurement is gaining more strategic importance within an organization, the expectations from this function are also increasing. This year, the procurement function will continue to deliver on traditional cost savings while focusing heavily on digital technologies and supplier synergies. Overall, 2019 seems like a promising year full of challenges and opportunities for procurement to undertake.
  - Thinking suppliers beyond the price
    Buyers cannot afford to communicate with suppliers just over the price. They need to involve them in more strategic decisions right at the initial planning phase. Suppliers thus become an integral part of any supply chain and can play a pivot role in making/breaking the backbone of the procurement.
  - Risk management – preparing for the unexpected
    - Availability: *Major world economies are continuously thriving to be prepared for the unexpected. With these uncertainties, the procurement function would be at the forefront of an organization for risk minimization*
    - Transparency: *Moreover, organizations are always struggling with internal risks arising due to lack of transparency. Being compliant with legal standards is just not enough these days.*
  - Increasing focus on indirect spending
    Indirect spending or tail spending follows the 80/20 rule, i.e., it constitutes 20% of the organization spent and involves 80% of the suppliers.
    The solution will minimize the maverick spending by negotiating the critical contract terms well in advance suppliers and streamline the complete contracting process.

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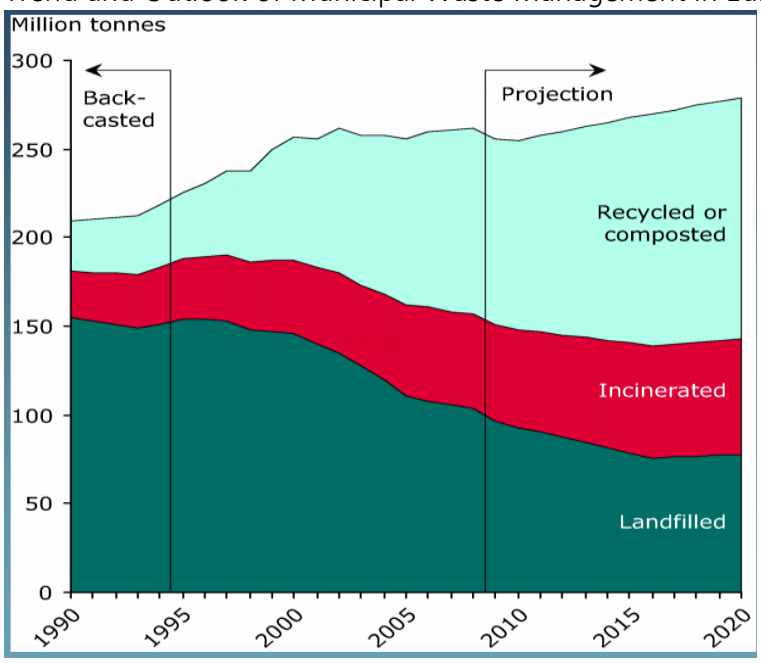
1.2.3 Political

- https://www.iswa.org/uploads/tx_iswaknowledgebase/Ozgur_Saki.pdf
  - Europe, like much of the industrialized world, is using an increasing amount of materials. The EU-27 average annual use of material resources is some 16 tonnes per person.
  - The overall trend in waste generation, including hazardous waste, is upwards.
  - The long-term goal is for the EU to become a recycling society, that seeks to avoid waste and uses waste as a resource.
  - New Targets
    - 2015 Separate collection: At least for paper, plastic, metal and glass
    - 2020 recycling rates of 50% for household and similar wastes (at least paper, plastic, metal and glass)
    - 2020 70% for construction and demolition waste

- Trend and Outlook of Municipal Waste Management in Europe

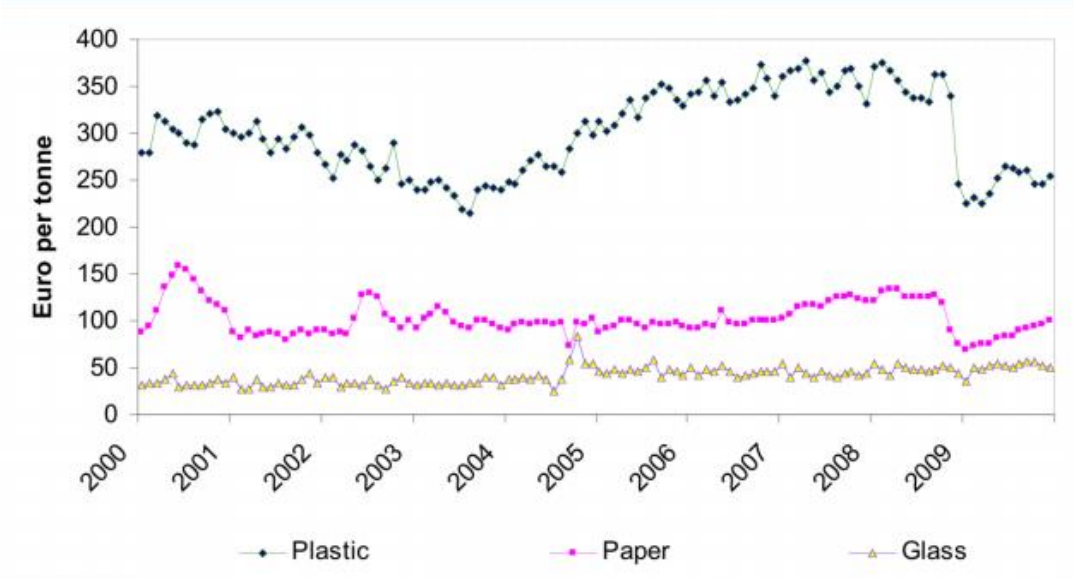


- Recycling Policies for Selected Waste Streams, ETC/SCP 2010

Typologies of instruments	Policy Instruments
Administrative	Landfill bans, incineration bans, material restrictions, eco-design requirements related to reuse/recycling, minimum recycled material content standards, source separation/collection requirements, waste prevention requirements, waste prevention targets, collection targets, landfill/incineration diversion targets, reuse targets, recycling targets, recovery targets
Administrative/economic	Producer take back requirements
Economic/Market Based	Deposit-refund systems, producer responsibility, taxes on virgin materials, taxes on hazardous substances, landfill taxes/charges, incineration taxes/charges, waste disposal taxes/fees/charges, recycling fees/charges, product taxes/ charges, tradable recycling credits
Informative	Information provision requirements, eco-labels

- Landfill tax in itself is a strong driver; 2. Landfill tax in combination with other initiatives such as a source separation mandate, specific recycling targets or a landfill ban is an even stronger driver; 3. Mandatory use of source separation seems to be a strong driver in countries without the use of a landfill taks
- Generally, recycling works best if a market for the recycled materials exists or can be created. Recycling had been favoured by rising prices for many secondary and primary materials in recent years. Recycling markets suffered during the economic crisis but seem

now to be recovering slowly.



1.2.4 Environmental

- Environmental impact of materials
  - Emission reduction
    - https://www.architectmagazine.com/practice/material-trends-to-watch-in-2019_o
  - Demand for building green
    - https://medium.com/@moxy_cerlos/building-materials-industry-is-going-green-2020-trends-and-forecast-5a487039424a
  - Weight reduction?
- Production of waste materials?
- Procurement
  - https://cerasis.com/industrial-procurement-trends/
    - Sustainability and Visibility Become a New Focus of Auditing
      Advanced auditing tools, including the use of outsourced auditing services, will be a driving force in maintaining compliance with regulations and upholding a positive image in the public eye
- https://ec.europa.eu/commission/presscorner/detail/en/IP_18_3846
  - Phasing out landfilling
    Landfilling of waste makes no sense in a circular economy and can pollute water, soil and air. By 2035 the amount of municipal waste landfilled must be reduced to 10% or less of the total amount of municipal waste generated.
  - Incentives
    The new legislation foresees more use of effective economic instruments and other measures in support of the waste hierarchy. Producers are given an important role in this transition by making them responsible for their products when they become waste.
  - Prevention
    The new legislation will place a particular focus on waste prevention and introduce important objectives for food waste in the EU and halting marine litter to help achieve the UN Sustainable Development Goals in these areas.
-

1.2.5 Social

- Fairtrade
- Perception of materials, fashion trends for interior design
  - https://www.heals.com/blog/heals-trend-report-2019-materials/

  - https://lodgingmagazine.com/six-trends-in-design-materials-for-2019/
  - https://news.infurma.es/designer/ambiente-trends-2020-new-styles-materials-themes-and-product-mixes-for-the-coming-year/21474
- Dossier duurzaamheid 2018 https://b-open.nl/wp-content/uploads/2018/10/Persbericht-Dossier-Duurzaam-2018_9-oktober-2018.pdf
  -
- Dossier duurzaamheid 2019 https://b-open.nl/wp-content/uploads/2019/10/persbericht_Dossier-Duurzaam-2019-091019.pdf
  -

1.2.6 Technology

- Procurement
  - https://cerasis.com/industrial-procurement-trends/
    - Companies Will Seek New Ways to Use Technology in Procurement
      Increase in use of technology in procurement due to global supply chain → digital supply chain
    - Integrated Procurement and Payment Systems Simplify the Process
    - Analytics Driven Procurement Will Take Center Stage as the Key Player in all the Industrial Procurement Trends
      Procurement becomes smarter and cognitive, meaning it will use more analytics-driven processes in decision-making and activities
-
- Material selection process
  - Materials genome: https://www.hindawi.com/journals/amse/2020/5903457/#abstract
    With the development of economy and science and technology, designing materials on demand and accurately controlling materials' properties have become the development trends of advanced materials.
- New types of materials
  - New (biobased) sources of materials:
    - https://www.eclectictrends.com/5-examples-of-sustainable-material-trends-part-i/
    - https://www.architectmagazine.com/practice/material-trends-to-watch-in-2019_o
    - https://wfmmedia.com/building-material-trends-2019/
    - https://materialscience.alliedacademies.com/2018/events-list/emerging-trends-in-materials-science
  - New production methods
    - http://crosstalk.cell.com/blog/the-editor-of-matter-on-5-materials-trends-to-watch
    - Rapid manufacturing
  - Surface design: https://www.scarletopus.com/2019/03/top-3-trends-surface-design-materials/
  - Added functionality in materials
    - https://wfmmedia.com/building-material-trends-2019/
    - http://crosstalk.cell.com/blog/the-editor-of-matter-on-5-materials-trends-to-watch
    - https://materialscience.alliedacademies.com/2018/events-list/emerging-trends-in-materials-science
  - Innovative materials
    - Flexible free-form materials
      https://www.tno.nl/en/focus-areas/industry/roadmaps/flexible-free-form-products/development-of-new-materials/
    - AI materials
      http://crosstalk.cell.com/blog/the-editor-of-matter-on-5-materials-trends-to-watch
    - Advanced structural materials
    - Smart materials
      https://www.materialstoday.com/amorphous/comment/keeping-pace-with-

innovations-advanced-materials/
https://www.alliedmarketresearch.com/smart-material-market

- Nanomaterials
  - https://www.longdom.org/open-access/market-analysis-2020-on-future-trends-on-material-science-and-nanotechnology-47547.html
  - https://www.nims.go.jp/eng/publicity/publication/hdfqf1000008bzaj-att/nims2020.pdf
  - https://www.papercrowd.com/c/future-trends-on-material-science-and-nanotechnology-2020/16445
  - https://www.asme.org/topics-resources/content/top-5-trends-materials-engineering
- file:///H:/My%20Documents/Studie/Afstuderen/Relevante%20documenten%20(nader%20te%20orderen)/10-Trends-WMRIF-WebVersion-2016.pdf
- ~~https://ceramics.org/ceramic-tech-today/materials-needs-for-the-future-wmrif-outlines-prominent-trends-and-challenges-in-materials-science-and-engineering~~
- https://materialsscience.annualcongress.com/events-list/trends-in-materials-science

1.3 SUSTAINABILITY

In addition to sustainable development within both mobility and material development, I also chose to research sustainability as its own goal to get the bigger picture of the sustainability context. For this, I looked at both sustainable development and consumer behaviour trends.

- https://www.sigmaonline.nl/2015/04/5-trends-die-de-circulaire-economie-gaan-ontketenen/
  - **1. Toenemende schaarste aan hulpbronnen**
    We consumeren nu onze natuurlijke hulpbronnen veel sneller dan we ze kunnen vervangen. Er zullen tekorten ontstaan, niet alleen aan tal van metalen, maar ook aan water. In 2030 zal de helft van de wereldbevolking in waterarme gebieden wonen.
  - **2. Urbanisatie zet door**
    Nu leeft meer dan de helft van de mensen in stedelijke gebieden, een trend die zich zal voortzetten. De Ellen MacArthur Foundation (ellenmacarthurfoundation.org/business/reports) ziet in urbanisatie ook kansen voor de circulaire economie. Urbanisatie leidt namelijk door steeds grotere concentraties van mensen voor circulaire productiewijzen ook tot relatieve kostenvermindering door schaalvoordelen, wat een voorwaarde is voor hergebruik van grondstoffen.
  - **3. Meer macht voor de consument**
    Met meer toegang tot data en social media verkrijgen consumenten ook meer zicht op duurzame producten en de gevolgen van huidige productiewijzen. Uit consumentensurveys blijkt ook dat bedrijven zich meer zouden moeten inzetten voor het oplossen van maatschappelijke problemen.
  - **4. De opkomst van de deeleconomie**
    In plaats van nieuwe producten te kopen, delen consumenten steeds vaker producten en diensten met elkaar. De opkomende deeleconomie in de VS is nu goed voor een jaaromzet van 26 miljard dollar. Het is een trend die zich zal versnellen naarmate er meer digitale technologieën worden ontwikkeld, die markten verbinden.
  - **5. (Lokale) zelfvoorziening**
    Een belangrijke trend is dat mensen liever zelf producten maken dan kopen. Ze voorzien liever zelf in hun basisbehoeften, dan zich afhankelijk te maken van het multinationale bedrijfsleven. Gecombineerd met 3D-printing, een technologie die zelfvoorziening in de hand werkt, ondersteunt dit zowel de biologische kringloop door recycling van plastics (grondstof voor 3D-printers) als de lokale economie.
- https://www.greenbiz.com/article/6-circular-economy-trends-will-shape-2020
  - 1. Policymakers seek to hold producers responsible for waste

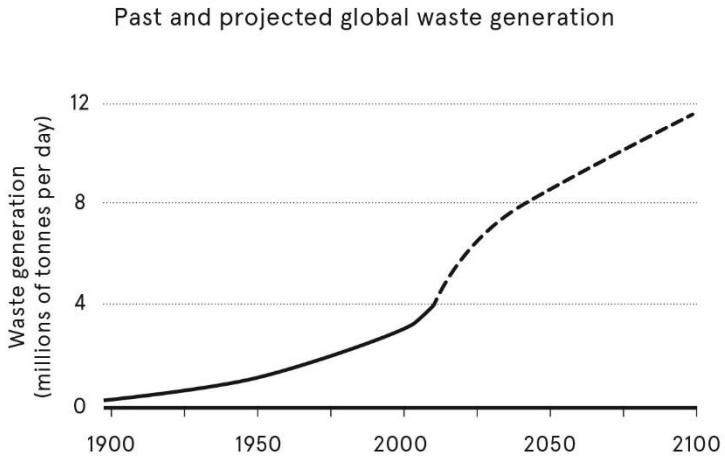
    - The policy landscape focused on end-of-life needs for products picked up in 2019. Companies are also more willing to collaborate on policy now, de Thomas said: "The question is: Is legislation going to be done to them or with them?"
    - Extended producer responsibility (EPR) bills [that] require manufacturers and retailers to contribute to the cost of collecting, recycling and disposing of their products at the end of life or use.
    - Europe and Canada already have EPR systems in place for packaging and goods such as electronics, batteries and cars, but Europe is moving towards "eco-modulation" that ties manufacturer costs for EPR programs to the recyclability or amount of recycled content in packaging.
- 2. Companies collaborate to reuse materials and packaging
    - (…) companies are increasingly partnering with supply chain members to solve materials challenges. We should see more such partnerships in 2020 and beyond.
    - "Producers are being stronger partners in the system," (…). Companies are better understanding what it means to use recycled content in packaging and ensuring that the packaging they're making can be recycled, he said.
    - (…) now that they're needing the material from the recycling system, they're paying more attention to how they put their product out in the marketplace.
- 3. Consumer brands explore refill models
    - With recycled plastic material meeting only 6 percent of demand today, companies with aggressive commitments to using recycled content in their packaging seek alternative solutions. Increasingly, some companies are testing new refill models that solve for waste and consumer convenience, while ensuring the integrity of the product inside.
    - Reusing, rather than recycling, glass bottles use less energy and improve the economics for materials recovery facilities by reducing the amount of broken glass in the system.
- 4. Chemical recycling moves closer to commercial scale
    - Chemical recycling breaks down plastics into simple components that have greater value and opportunity for reuse than plastic recycled through mechanical means such as grinding, shredding or re-granulating, which is how the majority of plastic is recycled today.
    - Companies, plastic manufacturers and recyclers increasingly seek to partner because of the limited supply of recycled material that's available at the quality that companies need to use for their packaging. Major brands in the plastics space and supply chain see this as part of the solution and know that they need to invest in it, Croke said.
    - [But] for this trend to take off, companies will need to sign more long-term contracts with chemical recyclers and find creative ways to share risk across the system.
- 5. Fast fashion is the new oceans plastics
    - (…) young, eco-conscious women are turning away from cheap, throwaway clothing.
    - Fast fashion, in fact, may well become the next ocean plastics as the industry comes under increasing pressure to become more sustainable.
    - Beyond zero waste solutions, some emerging approaches to reducing clothing waste include:
        - Durable & sustainable fashion; basics that can be mixed and matched
        - Subscription models; company takes unwanted clothing back for recycling
        - Rental clothing
        - Cotton recycling initiatives
- 6. Tensions rise over toxics
    - Environmental advocates have long urged greater attention to toxic chemicals in circular economy discussions. "The fundamental issue is that if you have toxics in the global economy, when you tighten the loop at the end of the cycle, what are you going to do with all of the legacy toxics?"

        - "When tainted plastic packaging is reused or recycled these toxic chemicals persist and may accumulate to worrisome levels until the packaging is retired, posing long-term threats to our health."
- https://www.tondo.tech/blog/2019/09/23/scenarios-and-trends-of-the-materials-towards%E2%80%8B-the-circular-economy/
    - Trends in corporates
        - According to a report by OCSE, it is estimated that the number of used resources will double by 2060. In particular, this fact involves specific sectors, as the packaging and the fashion ones, that are promising the recycling and the creation of biomaterials starting from 2020/2030.
        - However, there are no doubts about the possibilities of recycling, but there could be problems about who carry out the process: some corporates produce recyclable products, but they are not recycled. For this reason, it exists the idea that the circular economy is uneconomic: but this is not the truth because multiple international cases prove the contrary.
        - Many of these start from the principle of being "biomaterials", material that are easily biodegradable and, or, compostable;
        - there are other recyclable materials that are recyclable only through very specific processes and methods. This is very worrying because, it is possible to order recyclable products, but it is very hard for consumers to manage the end-life of the products. We can say that corporates have to play a more important role in managing the recycling of materials, for example, by creating a clause that specifies the end-life of the products in the patents.
    - Materials for rent
        - The existing trends such as resource scarcity, world population growth and the increase in demand for goods and services will bring to the unavoidable use of materials for rent. That means that the consumer will receive from the firm goods that are provided ad a service, to hand back at the end of the same service. This is the reason why the durability of the raw material is so important.
        - There is a passage from goods to services, producers will be in the front line to recover used things for new consumers. The durability of the materials should be longer to affect the market and to connect to this new vision of the future.
    - Measurement of circularity
        - To understand how sustainable a product is, it is important to consider the economic efficiency in the resource use management, (…) that is not the measurement of the efficient use of resources, but the measurement of the economy in the resource use management as input and output.
        - It could be necessary to underline the results of the Circular Economy, by indicating the quantity and the cost of the used material and the quantity, the cost and the revenue of the material managed during the end-of-life considering all the circle.
- https://www.circulairondernemen.nl/uploads/277bc6420cb2d2a317e913e669a9ed12.pdf
    - VOLITALITY OF RAW MATERIAL PRICES
        - It is a factor, next to availability of raw materials, which is of direct impact on business and production continuity. Although outsiders often think that companies are particularly involved in turnover and profit, business continuity is often the most important factor.
        - There are two primary reactions1 possible: the one is a better organization by 'purchasing alliances' to achieve for better flows of raw materials. The second strategy is the organization of the management of raw materials, by seeing products as a temporary storage of materials to subsequently be the basis for new production.
    - FINITE AVAILABILITY RAW MATERIALS
        - (1) depletion of raw materials, (2) negative impact of intervention in natural systems for mining, (3) some raw materials are only extractable in a limited number of places in the world.

    - Dependency on raw materials and virgin materials is a risk to resilience in long term economics. Assessing a longer scale, the expectation is that availability of raw materials will be one of the biggest security risks of this century.
- FROM OWNERSHIP TO USE
    - Now, companies see the access or performance over ownership as a good business model (…). Property does not count, but people and businesses want to access or 'performance'3: performance, service and pay for use.
    - For the companies this is a chance for long-term relationships with the customer. The product remains the property of the producer and also as a 'resource-bank' for next stages in production.
- PRODUCT-SERVICE DESIGN
    - Products are often more or less of equal quality and 'do what they do'. Clearly it is that the associated service makes the distinction. The current consumer is accustomed to good quality but expects an 'out-standing' service. 'Customer Experiences' are often appointed as an important tool to strengthen customer satisfaction.
    - Newer thinking is linking into 'Service design' where the experience, the product and the right time are being combined. The supplier who combines product and services in a smart way, may count on loyal customers.
- UPGRADING SOCIETY
    - The product-life-cycle is not determined anymore by technical life, but is determined by the usage life. A part of these needs can be met by upgrading existing products (think of the self-steering Tesla by an automated upgrade), partly a higher velocity in production is the answer. From a circular perspective both options are good to meet, provided that the design takes it into account.
    - The upgrading society is not asking for 'extended durability' but smarter design of products and services. A good example is modularity, the ability to add / change specific modules.
- FLEXIBILITY AS NEW STANDARD
    - Flexibility seems to be the new way of organizing our economics.
    - Organizations leave their 'old assets' such as private office buildings, organizations are more and more organized as cooperatives
    - Flexibility in production plays a role: the customer wants increasingly 'tailor-made' solutions from the producer/manufacturer
- ENERGETIC SOCIETY
    - Also known as the 'enterprising society', in which citizens take initiatives as the government and institutions/companies do not offer an adequate service.
    - The creation of private cooperative working relationships makes it possible to work on the implementation of entrepreneurial social objectives
    - For a circular economy this is of interest because these companies are leaders in the transfer of 'ownership to use', from 'product to services' and of central and decentralized organizations. All these examples provide resilience to the systems. reduces chances of a crash in production/operation.
- RISK AWARENESS AND DENIAL
    - We seem to live in a risk-free society, as we experience from day to day. The large risks as flooding, climate change or resource-scarcity, we do recognize but, mainly our reflex is denial. The problems seem too big or we cannot impact them. Denial of risks is a powerful mechanism, individually but also as an organization and as a society.
    - To learn and acknowledge these risks makes us more resilient, especially if something unexpected appears to happen. Responding to risks with 'smart' and strong buffers, seems to be a reflex to this trend.
- DESIGN FOR CIRCULARITY
    - A key factor for use and re-use of products and components is a careful and appropriate design. More and more companies try to make their new products with 'refurbishment' of parts that are used in previous products.

        - This requires a certain degree of standarisation for those parts where innovation does not play a major role.
        - In addition, attention to design is necessary for recovery of high-quality raw materials, and small products (which are dispersed in the waste stream) through recycling operations. Re-use through eBay and other sites has a large market. These 'second markets' are becoming increasingly more of interest for entrepreneurs, which are not shy for recreating quality.
        - Repairability of course also plays a major role. All this is summarized in the eight R's: Rethink, Reduce, Re-use, Repair, Re-furbish/ Remanufacturing, Recycling and Recover. For each producer and of course as design options for each product designer to internalize.
    - INDIVIDUAL AND PLURALISM
        - People are used to 'owning' and all people do it.
        - The combination of individuality and diversity offers opportunities for new entrepreneurship based on, again, a high quality of product-services. This asks for smart design, adaptive construction methods/assembly and appropriate contacts with those customer(s).
    - GUILT FREE CONSUMPTION
        - "Fueled by a pervasive awareness of the conflicts between their consumerist impulses and their aspirations to be 'good', experienced consumers are increasingly wracked with guilt. The result? A growing hunger for a new kind of consumption: one free from worry (or at least with less worry) about its negative impact, yet that allows continued indulgence." – Trendwatching
        - The consumer wants to consume and do so preferably without guilt. This group does not feel directly capable to make sustainable choices and expects the producer or supplier to play an role to become responsible. They expect the supermarket, clothing store and all others, to deliver quality and the corresponding responsibility.
        -

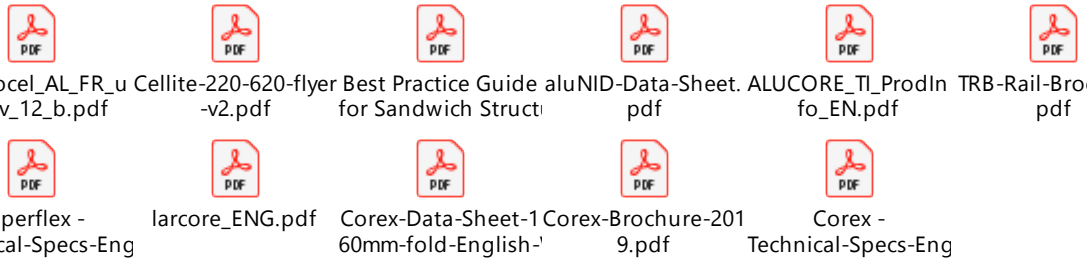
- https://medium.com/global-design-futures/circular-economy-d5afa6ddb15a
    - The linear consumption model of take, make and dispose with the increasing pace of product turnovers is not only unsustainable but also inefficient. We fill our oceans with waste and at the same time we will soon run out of natural resources (Ellen MacArthur Foundation, 2013). It is estimated that we will consume three times more resources annually in 2050 (Burrow, 2017) and by 2025, waste production will be doubled (Hoornweg and Bhada-Tata, 2012).
        -



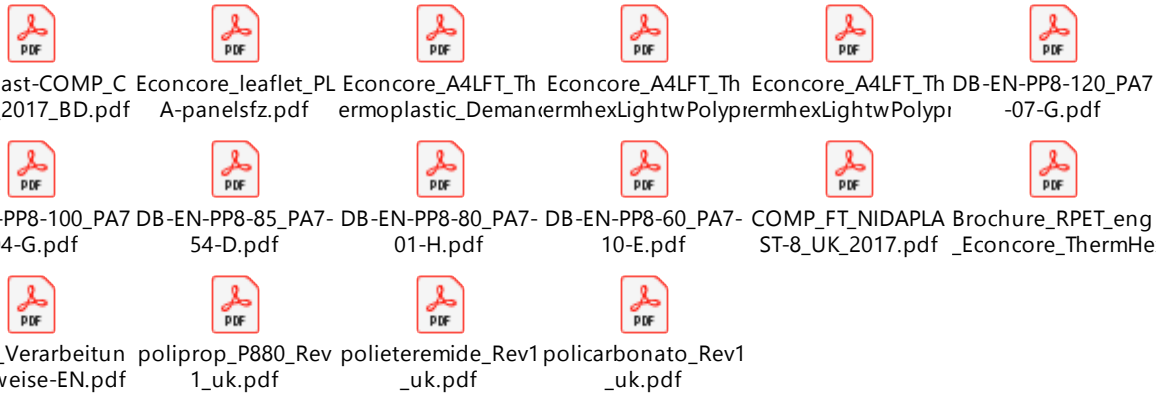
    - Designing around people's needs — not products

- Beside repairing, remanufacturing and recycling, change will happen when the lifetime of products increases to reduce the manufacturing of new products (CEC Expert, 2016).
- The current economic model is based on growth, where profit sits on single units. It follows the paradigm of sell more, earn more which needs the assumption of disposability. Longer lasting products and the reduction of consumption would mean a decrease in growth and therefore an unprofitable business.
  In a circular economy, it will be not anymore about the quantity of products that will be sold, but about products that last as long as possible (Business Debate, 2016).
- Not only products have to be optimized for multiple cycles of reuse and remanufacturing (Braungart, McDonough, 2009) but also business models have to be redesigned.

G MATERIAL REPORTS



A.1 PLASTIC



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DESIGN FOR our future

TU Delft

IDE Master Graduation

Project team, Procedural checks and personal Project brief

This document contains the agreements made between student and supervisory team about the student's IDE Master Graduation Project. This document can also include the involvement of an external organisation, however, it does not cover any legal employment relationship that the student and the client (might) agree upon. Next to that, this document facilitates the required procedural checks. In this document:

- The student defines the team, what he/she is going to do/deliver and how that will come about.
- SSC E&SA (Shared Service Center, Education & Student Affairs) reports on the student's registration and study progress.
- IDE's Board of Examiners confirms if the student is allowed to start the Graduation Project.

USE ADOBE ACROBAT READER TO OPEN, EDIT AND SAVE THIS DOCUMENT

Download again and reopen in case you tried other software, such as Preview (Mac) or a webbrowser.

STUDENT DATA & MASTER PROGRAMME

Save this form according the format "IDE Master Graduation Project Brief_familyname_firstname_studentnumber_dd-mm-yyyy".
Complete all blue parts of the form and include the approved Project Brief in your Graduation Report as Appendix 1 !

family name: van Oudheusden
initials: A A given name: Aurelia Alma
student number: 4347684
street & no.: ----------
zipcode & city: ----------
country: ----------
phone: ----------
email: ----------

Your master programme (only select the options that apply to you):

IDE master(s): ★ IPD ☐ DfI ☐ SPD
2nd non-IDE master:
individual programme: - - (give date of approval)
honours programme: ☐ Honours Programme Master
specialisation / annotation: ☐ Medisign
★ Tech. in Sustainable Design
☐ Entrepeneurship

SUPERVISORY TEAM **

Fill in the required data for the supervisory team members. Please check the instructions on the right !

** chair: Prof. dr. Ruud Balkenende dept. / section: CPD
** mentor: ir. Ehsan Baha dept. / section: DOS/MOD
2nd mentor: Ilse de Vos-van Eekeren
organisation: Nederlandse Spoorwegen
city: Utrecht country: The Netherlands

comments (optional)

Chair should request the IDE Board of Examiners for approval of a non-IDE mentor, including a motivation letter and c.v..

Second mentor only applies in case the assignment is hosted by an external organisation.

Ensure a heterogeneous team. In case you wish to include two team members from the same section, please explain why.

APPROVAL PROJECT BRIEF

To be filled in by the chair of the supervisory team.

chair _____ date ____-____-____ signature _____

CHECK STUDY PROGRESS

To be filled in by the SSC E&SA (Shared Service Center, Education & Student Affairs), after approval of the project brief by the Chair.
The study progress will be checked for a 2nd time just before the green light meeting.

Master electives no. of EC accumulated in total: _____ EC

Of which, taking the conditional requirements into account, can be part of the exam programme _____ EC

List of electives obtained before the third semester without approval of the BoE

YES all 1st year master courses passed

NO missing 1st year master courses are:

name _____ date ____-____-____ signature _____

FORMAL APPROVAL GRADUATION PROJECT

To be filled in by the Board of Examiners of IDE TU Delft. Please check the supervisory team and study the parts of the brief marked **.
Next, please assess, (dis)approve and sign this Project Brief, by using the criteria below.

- Does the project fit within the (MSc)-programme of the student (taking into account, if described, the activities done next to the obligatory MSc specific courses)?
- Is the level of the project challenging enough for a MSc IDE graduating student?
- Is the project expected to be doable within 100 working days/20 weeks ?
- Does the composition of the supervisory team comply with the regulations and fit the assignment ?

Content: APPROVED NOT APPROVED

Procedure: APPROVED NOT APPROVED

comments

name _____ date ____-____-____ signature _____

Initials & Name A A van Oudheusden Student number 4347684

Title of Project Circularity in the Dutch Train

Circularity in the Dutch Train — project title

Please state the title of your graduation project (above) and the start date and end date (below). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

start date 09 - 03 - 2020 — 07 - 08 - 2020 end date

INTRODUCTION **

Please describe, the context of your project, and address the main stakeholders (interests) within this context in a concise yet complete manner. Who are involved, what do they value and how do they currently operate within the given context? What are the main opportunities and limitations you are currently aware of (cultural- and social norms, resources (time, money,...), technology, ...).

CONTEXT
NS (Nederlandse Spoorwegen, the Dutch railway company) wants to transition towards fully circular trains. To this end, it is tried to reuse as much material as possible in the most high-grade manner, measured by the Ladder van Lansink (Figure 1). In this process the following phases can be distinguished:
- Building: this is done by external parties, contracted by NS under strict regulations and criteria.
- Maintenance: cleaning and repairing the train to increase its lifetime/
- Modernisation: overhauling a train of 20ys old to double its lifetime, reusing as much material as possible (Figure 2).
- End-of-life;
o "Plukken": stripping parts for internal use in other trains
o "Oogsten": stripping parts to sell to external companies for upcycling
o Circular dismantling: taking apart the train and recycling the materials where possible
Within my project I will focus on the material streams from trains: the train car body, the wheel sets, and the train interior.

STAKEHOLDERS
Within NS: NS Sustainability, NS Operations (circular dismantling team, modernisation, service, maintenance and cleaning), legal department, TMSB table members, QHSE
What do internal NS stakeholders value: the goal is set to be fully circular in 2030. However, this must be done in a safe and thorough manner, taking into account aspects such as legal requirements and economic feasibility

Outside NS: train builders, train dismantlers, recycling companies, current partners that upcycle train materials
What do external stakeholders value: all parties are looking for ways to fit to the criteria while making minimal adjustments to their current processes. Sustainability is becoming more and more important, but they also need to be able to make money and work safely. Additionally, the parties that work at the back end of the process want to know the product specifications such as volume and material contents.

OPPORTUNITIES/LIMITATIONS
Opportunities:
+ There is an increased motivation towards sustainability within NS and in general
+ NS is seen as a leader in the field of sustainable mobility.
+ NS is a well-known company with high esteem and a lot of connections.
+ NS is a large company; they are able to generate large volumes of continuous material streams. This means they can generate a large impact.

Limitations:
- NS can be a conservative company that wants to play it safe due to fear of negative critique/perception
- Adjusting current processes costs time, money and effort, with a lot of internal parties/stakeholders involved.
- NS only has a facilitating role. They cannot make their own trains or upcycle their own materials, but need to contract external parties for that. This limits their flexibility.
- The train market is very conservative and prefers to play it safe.

space available for images / figures on next page

introduction (continued): space for images

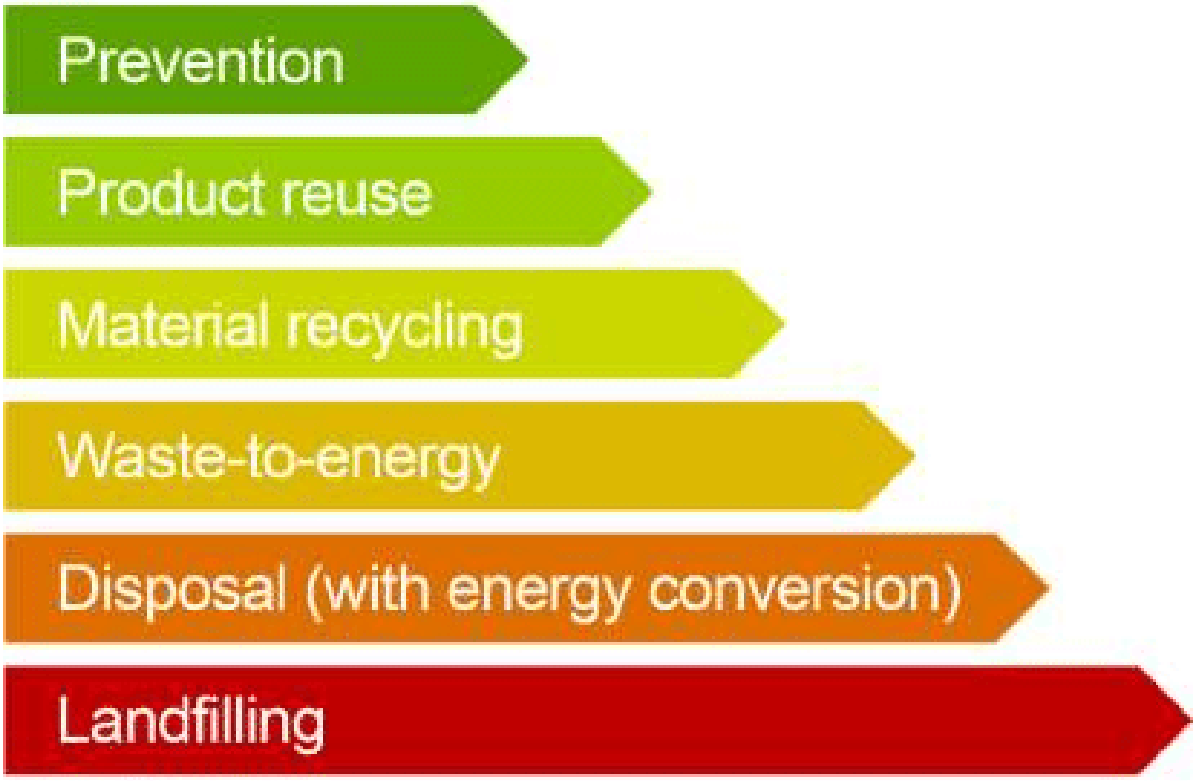

image / figure 1: The Ladder van Lansink

image / figure 2: A train halfway through the modernisation process

Initials & Name _____ Student number _____

Title of Project _____

PROBLEM DEFINITION **

Limit and define the scope and solution space of your project to one that is manageable within one Master Graduation Project of 30 EC (= 20 full time weeks or 100 working days) and clearly indicate what issue(s) should be addressed in this project.

The NS wants to transition towards fully circular trains and remain a leader in the field of sustainability.
To achieve this, there are multiple issues that need to be adressed:
- Not all materials have circular end-of-life treatment options at the moment. The heavier constructs, such as the steel casco (25 wt%), are mostly recyclable. However, there is a remaining stream of material that has no destination yet. This is mainly the interior parts of the train as these are made from composite/hybrid materials (e.g. HPL, glass fibre-polyester).
- There is no good overview of problem scale and timeline, nor of what materials to expect when. This makes the problem very inconcrete and hard to anticipate which actions are necessary.
- At the moment, there are no sufficient sustainability specifications or a specific way to measure sustainability. This makes it hard to make decisions and compare options.
- All the information that is available is very widespread and textual, there is no comprehensive visual overview.

ASSIGNMENT **

State in 2 or 3 sentences what you are going to research, design, create and / or generate, that will solve (part of) the issue(s) pointed out in "problem definition". Then illustrate this assignment by indicating what kind of solution you expect and / or aim to deliver, for instance: a product, a product-service combination, a strategy illustrated through product or product-service combination ideas, ... In case of a Specialisation and/or Annotation, make sure the assignment reflects this/these.

I will investigate the current scenario and how to transition from here towards fully circular trains. Additionally, I will provide recommendations on how to improve circularity in train design, and illustrate this with prototypes.

I will create a design roadmap to show the transition towards circular trains. In this roadmap, the problems and opportunities are indicated, as well as the actions necessary to address these.
Preferably, the roadmap would be interactive to allow the shifting data and to be able to scale/select in the overview.

For the recommendations, I will develop a list of specifications that can be used in the contracting for train building/modernisation. I want to illustrate these with concrete examples on how to meet the criteria, supported by the use of annotated portfolios and prototypes.

Initials & Name _____ Student number _____

Title of Project _____

PLANNING AND APPROACH **

Include a Gantt Chart (replace the example below - more examples can be found in Manual 2) that shows the different phases of your project, deliverables you have in mind, meetings, and how you plan to spend your time. Please note that all activities should fit within the given net time of 30 EC = 20 full time weeks or 100 working days, and your planning should include a kick-off meeting, mid-term meeting, green light meeting and graduation ceremony. Illustrate your Gantt Chart by, for instance, explaining your approach, and please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any, for instance because of holidays or parallel activities.

start date 9 - 3 - 2020 7 - 8 - 2020 end date

I want to make use of the 1:10:100 approach, as this will give me a better overview of the project. This means that I will start with a rough first draft of my whole project in one day in week 2. Then, I will do a second, more elaborate round in the next ten days. After analyzing this and discussing it with mentors and stakeholders, I will continue to work on the project in a detailed and in-depth manner.
See below a quick overview of my project:
Week 1: KICK-OFF; Introduction & context
Week 2-4: "Project in 1 day", followed by project in 10 days. This will mainly consist out of collecting data and doing the first rough analyses and decision making. Afterwards, I will analyse the results
Week 5-7: Start on more thorough and detailed analysis of the gathered information, and prepare the midterm.
Week 8: MIDTERM
Week 9-10: Decision making, assess current impact & set up current scenario
BREAK
Week 11-12: Set-up and assess future scenarios
Week 13-14: Find & define improvements, write recommendations for new trains
Week 15: Prepare greenlight
Week 16: GREENLIGHT
Week 17-19: Buffer time, checking with stakeholders, reporting
Week 20: GRADUATION

This project overview is very detailed; I understand that interdependencies will cause activities to shift, but I chose to create a detailed overview to be able to show my approach in the project.

Initials & Name _____ Student number _____

Title of Project _____

MOTIVATION AND PERSONAL AMBITIONS

Explain why you set up this project, what competences you want to prove and learn. For example: acquired competences from your MSc programme, the elective semester, extra-curricular activities (etc.) and point out the competences you have yet developed. Optionally, describe which personal learning ambitions you explicitly want to address in this project, on top of the learning objectives of the Graduation Project, such as: in depth knowledge a on specific subject, broadening your competences or experimenting with a specific tool and/or methodology, ... Stick to no more than five ambitions.

MOTIVATION
Sustainability has been a passion of me for a long time now. I did a minor on Sustainable Design Engineering in my bachelor, which sparked me to make sustainability my specialty. In my master, I combined it with my keen interest for materials and did a research project on composite recycling.
However, as much as I like research, all these projects remained very theoretical and weren't put into practice. During my internship at NS I saw the practical side of sustainability, all aspects involved within a business context, and how you can actually realise an impact.

For my graduation I want to combine my interests of sustainability, materials and research with the practical side of business and impact realisation.

LEARNING OBJECTIVES
- Expand my material knowledge
(on top of courses and electives I already followed such as Industriele Productie (BSc), my composite research project, Designing with Composites and Digital Materials (MSc electives)).

- Experience how it is to carry my own large research project within a business context

- Learn how to involve/integrate ongoing NS projects within my own project

- Learn what possibilities there are in measuring sustainability

- Experience corporate decision making and argumentation

FINAL COMMENTS

In case your project brief needs final comments, please add any information you think is relevant.

Initials & Name _____ Student number _____

Title of Project _____