Julia Kloet

Circularity in Railway

How Circularity Can Be Applied In Railway

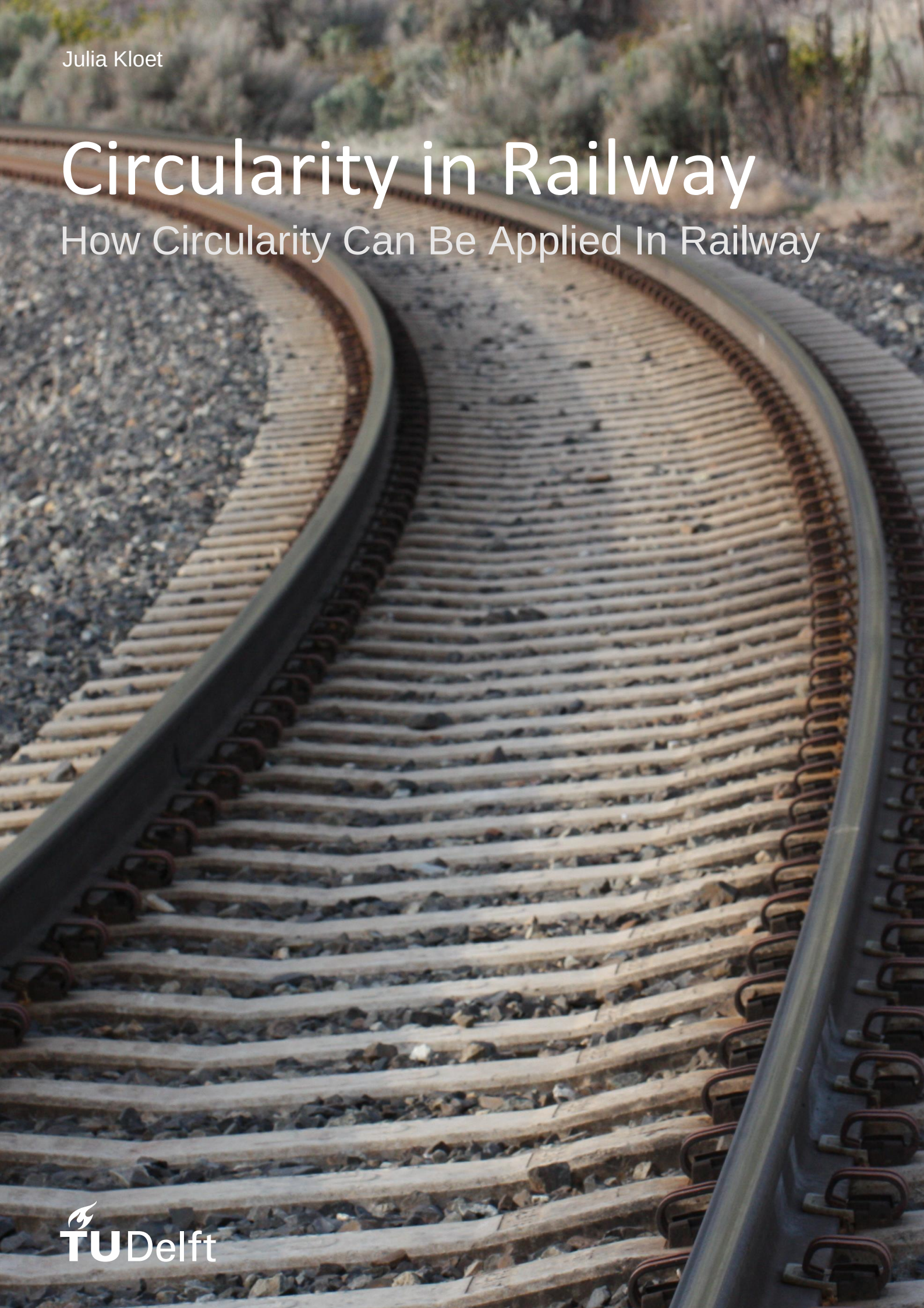

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Photo front page (Siegmund, 2010)

Circularity in Railway

How can circularity be applied in railway?

Final Report

By

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Preface

This report is written as the final work of the bachelor Civil Engineering at the faculty of Civil Engineering and Geo-sciences at Delft University of Technology. For this final work a master direction had to be chosen and within this direction one could pick a subject of interest. In this case the structural engineering direction was chosen with ‘Circularity in Railway’ as subject. For this report the meaning of circularity and the possible application in railway is researched.

I would like to express my thanks to the TU Delft faculty of Civil Engineering and Geo-sciences for so carefully and dynamic consort, in spite of the constantly changing rules due to the current COVID-19 pandemic. Special thanks go to V.L. Markine and W. Cao for their help and advises during the research process.

J. Kloet
Delft, June 2021

Summary

Circularity is an actual topic in the railway industry. Due to the increasing demand for raw materials, a scarcity of raw materials is arising. Therefore the prices are rising. Becoming circular is one of the solutions to prevent this from becoming a serious problem. However, companies cannot become circular easily, it is a complex transition. Regarding this transition, the research question is formulated: How can circularity be applied in railway? To acquire information to answer this research question, information is gathered from literature and interviews. Furthermore, the report is based on own visions on the problem.

To answer the research question, the definition of circularity first had to be clear. Circularity is based on the idea that there is no waste. This can be achieved by designing by the 3R-principle; Reduce, Reuse and Recycle. Second, the reasons for circularity were explained. The three major reasons are sustainability, scarcity of raw materials and the possibility of new employment. Sustainability is a crucial aspect, because the building industry and the railway industry are exceptionally polluting industries with high carbon dioxide emissions. Third, the stakeholders were evaluated. The government is one of the main stakeholders, since they can set goals for whole industries and stimulate them to achieve these. As a result of the Agreement of Paris 2016 the government decided that the railway industry has to be circular in 2050. For the railway industry, NS and ProRail are big parties too. They set the tone in the Netherlands and have a lot of influence in the Netherlands to initiate the transition. As fourth, other industries were evaluated on how they incorporate circularity. This is useful, because the railway industry and some other industries show overlap in the materials they use and could work together in the future with the reuse and recycling of materials. Finally, the options for circular applications in the railway industry were explored. The possibilities are investigated per component. Research shows that some components are already suited for reuse in their current form, like sleepers, ballast materials and track. For the other parts more innovative ideas are needed to reuse or recycle the materials. For example, materials or products from trains can be used well in other industries than just railway. However, the designs for the trains itself can also be improved by reduce the amount of steel or plastics that is used. Not only the technical aspect was evaluated, the organizational aspect as well. The traditional way of working is that the rail is designed for minimal risks and maximum safety. On the other hand, some risks have to be taken to become circular. Therefore, the mindset within the companies has to change and people have to be educated on implementing circularity in projects.

In conclusion, it can be said that the railway industry has potential to become completely circular. However, it is a complex transition and many more options have to be explored Besides the technical aspects, the main thing that has to change is the way of working in the companies, because that is where the transformation starts. The mindset has to be changed in order to achieve the goals that are set.

Contents

Introduction

Circularity is an actual topic in the building and construction industry. One of the causes is the increasing imminent scarcity of raw materials. Right now, the industry is based on making building and construction materials from raw products. But this system is not sustainable, because one day, the materials will not be available anymore and they keep becoming more expensive the rarer they are. In the railway industry, parts of railways are not always removed because they are broken, but to make place for newer technologies. That means that the waste product is not completely useless. So far, circularity is not getting that much attention in railway, but it looks like it could be a good solution. Therefore, something has to change in order to prevent a shortage of materials to keep building new constructions.

The objective of this report is to find out how circularity can be applied in railway. That starts with defining the actual definition of the word circularity and to find out what it can mean in railway. Before circularity can be applied in railway, the reason why has to be specified. Otherwise the stakeholders can never be persuaded to invest any money in this. Because if circularity is really going to be carried through, it will cost a lot of money. Money is a critical factor in this case and therefore it should be looked at who should take the initiative. Should that be companies like NS and ProRail or the government? And should the government set any goals and give subsidy or are they already doing these things? Those questions will be answered in this report. Furthermore, it is necessary to see where circularity can be intertwined in railway. For example, can it be applied in the actual track or more around it, like in the stations or with sound barriers? Those are the main questions for this problem and they will be answered in this report.

The report starts of with de clarification of the definition of circularity in chapter 1. Chapter 2 will discuss the reasons to implement circularity. Then, in chapter 3 the stakeholders in the Dutch railway system will be analysed. To compare the differences and possibilities, in chapter 4 the application of circularity in other industries will be described. In the final chapter, chapter 5, the application of circularity in railway will be defined. Chapter 6 includes the conclusion and chapter 7 the discussion.

1 Definition of Circularity

To understand how circularity can be applied in railway, the definition of what circularity actually is, needs to be clear. People see circularity at part of a futuristic vision, something that still has to be figured out. Partly, that is true, in many industries it is quite a puzzle to implement a circular economy. But circularity was already present in the medieval society. Castles that became superfluous, were broken down and the stones were reused to build something new (Stahel, 2019).

To explain the differences in a circular economy, it is good to know what the standard currently is. In most cases there is a (partly) linear economy. That starts with raw materials that are used to manufacture products. After people are done using it, it is demolished or energy is recovered. For example by decomposing materials into heat, emissions and ashes (van Buren et al., 2016). This way the life cycle has ended after the recovery of energy. However, not all materials are going to waste. Recycling is growing steadily and a recycling economy is even standard in some industries, like the production of glass and plastic. But in a recycling economy, raw materials are still necessary to keep the production going and when the products reach the end-of-life state some of the materials end up in waste. Recycling is a good step into the direction of a circular economy. Nevertheless, it is not a closed loop yet and improvements can be made. In many cases, the recycled product is processed in a way that leads to a decreasing quality of the product and therefore it is seen as an inferior product (Frederiksen & Technical University of Denmark, 2018). Figure 1 gives a clear image of the differences in a linear and circular economy.

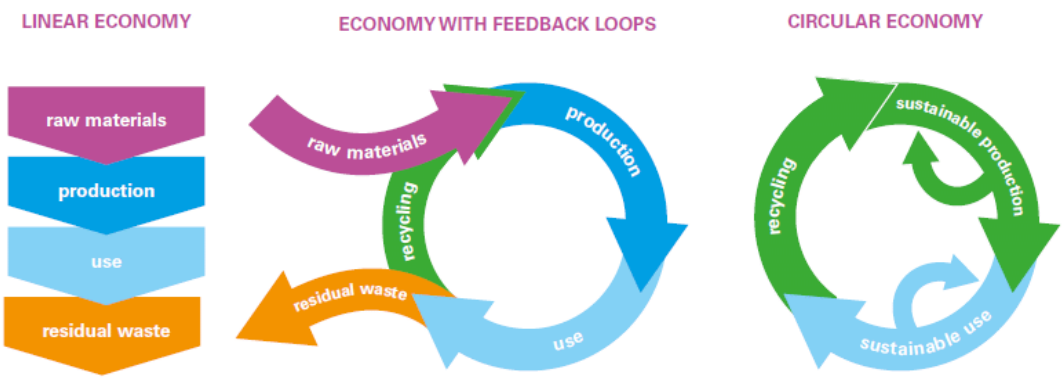

Figure 1 Differences between linear and circular economy (Özdenkçi, 2017)

To simplify the circular economy the 3R principle can be used. The 3R principle is considered to be the basis of the circular economy. 3R represents Reduction, Reuse and Recycle (Ghisellini et al., 2016).

It starts with reduction, because in the design process it is advantageous to minimize the amount of materials that are needed in the construction. This is desirable from a cost point of view, but also from a view of sustainability. Reduce can also be interpreted in a way that in a circular economy one should design to reduce waste throughout the entire life-cycle chain (López Ruiz et al., 2020). This is also known as waste management and is an prime aspect of circularity.

Reuse is rather straightforward, but nonetheless a critical point in the circular economy. Without reuse it is a simple linear economy. In the design process this has to be taken into account, because it can done in multiple ways. One of them is to make a construction demountable, so that whole parts can be used in a new construction. The other one is that parts can be reused for a completely different purpose or in another industry.

Recycling is more common and also generally known by the large public. This is because paper, plastic and glass are being separated from the “normal” waste for a few years now. The difference between reuse and recycling is that during the recycling process the product has been changed in a way which is not reversable anymore. A way of recycling is melting it or shredding it and using it for something else. An relevant note is that this is the way things are handled in western countries, but in many Third World countries all waste is mixed and a lot of progress has to be made. In the building industry it is a hot topic as well. For example, demolished concrete and masonry are being recycling more and more, but still, raw material has to be added to meet the quality requirements (Hansen, 1992). In the end, recycling is the least sustainable option compared to the other principles reduce and reuse (Ghisellini et al., 2016).

So, in conclusion, it can be said that circularity is reached when the use of raw materials is banished and all new products are made from recycled and reused materials. In some industries this is already the standard, but in many, this is still a big challenge. Many people see recycling as a big part of circularity, but it is actually reuse and reduce where we should focus on. Why we, as a society, should make circularity the new normal and how to do it, will be explained in the next chapters.

2 Reasons to Implement Circularity

As mentioned in the first chapter, circularity is not that new. What is, is the motivation of becoming a circular economy. In this chapter the question is what we can gain from circularity. Circularity is seen as a new business model that will lead to a more sustainable development and harmonious society (Ghisellini et al., 2016). The most common known reason is sustainability, but scarcity of raw materials and possible new employment are crucial as well.

2.1 Sustainability / environment

Circularity will have a direct and large impact on the environmental degradation. At the moment, society is breaking down the earth and is working on depletion of materials. With the growing population and increasing demands because of increasing welfare, this will only worsen.

Concrete is the most-used construction material. It is a mixture of cement, aggregates (sand and gravel), water and air. Sometimes chemical admixtures are used, depending on the desired function. This production has a large environmental impact. To start with the most basic ingredient: water; In 2012 9% of the global industrial water withdrawals was used for the production of concrete. This was 1.2% of the entire global water withdrawal, which is an enormous amount of water. That is the first problem. The second problem with this water demand is that it is expected that in 2050 75% of this water demand will occur at locations that are already in water stress (Miller et al., 2018). This way, the water scarcity will even worsen. Another critical ingredient of concrete is cement. Cement production is known for being responsible for 5% of the global carbon dioxide (CO_2) emissions. With the increasing demand for cement (not only for concrete), the carbon dioxide emissions will enlarge as well (Hasanbeigi et al., 2012). Besides that, the production of concrete contributes to a large amount of air pollutants emissions. For example, it contributes to the nitrogen oxide emissions (approximately 7.8% of the total in 2019), sulfur oxide emissions (4.8%) and atmospheric aerosol particles (Miller & Moore, 2020). All of these are unwanted in the air in large amounts, because it is harmful for the environment as well for the health of both humans and animals.

Another widely used construction material is steel. The production of steel is an extremely energy-intensive industry. Every year the steel industry is responsible for 5% of the global energy consumption. The steel industry is also accountable for 3-4% of the global carbon dioxide emissions (Xu & Cang, 2010).

So, it can be said that many materials that are used in the railway industry, like concrete and steel, are causing a lot of damage to the environment and are therefore not sustainable. The 3R principle from chapter 1 is applicable for these materials; It is essential to reduce the use and to reuse the already existing constructions as much as possible to reduce the impact on the environment.

2.2 Scarcity

Raw materials keep becoming more scarce. This is because of the increasing demand, partly due to the increasing world population. Because of the scarcity, prices of raw materials are rising and with the rising of the prices of the raw materials comes the rising of the prices of the products. The prices of raw materials have even doubled since 2000. Besides that, countries will be depending upon each other, which is not desirable, because it can influence political power. In some industries this is already notable. In the gas industry for example, where Russia literally has a lot of power (van Buren et al., 2016).

The Netherlands is greatly depending on raw materials from abroad. It actually imports 68% of its raw materials (161 billion kilogram in 2010). When also looking at semi-finished and finished products, this number ends up to be three times higher. In fact, Europe as a whole region, is much depending on import of raw products, so it would definitely be beneficial for Europe to be less vulnerable (van Buren et al., 2016).

2.3 New employment

New employment is not the first thing people will think about when talking about circularity, but circularity actually has considerable potential to create new employment. Circularity will cause a big change in the way that the industries are set up and if the production chain is completely changed, this could cause new employment. The question is how much, because there are also people who will lose their job or they will be assigned to those new positions. However, the difference between the jobs that will disappear and the jobs where will be demand for is, that the first one mostly takes place in countries with low wages. The new jobs will require people with organization or smart logistic skills, with knowledge of the latest researches on reduction, reuse and recycling and quality control. That causes a shift of the locations for the jobs to the more western countries (van Buren et al., 2016).

Another reason why more jobs arise, is that the demand for the new kind of products increase and therefore more people are needed (Horbach & Rammer, 2019). How much new employment will be created is hard to say. Several parties have done research, but the outcomes are for example: “Employment in new technologies, business practices or shifts in professions that yield improved energy efficiency are difficult to separate from regular employment, as they occur in existing industries and achieve the same economic output and level of well-being but with less energy.” (Meyer & Sommer, 2014). Those outcomes show that it is hard to precisely measure what kind of new employment is due to a circular economy, but all agree that new and more employment is created (Burger et al., 2019).

2.4 Conclusion

In conclusion, there are several reasons for implementing circularity in railway. The most common known is sustainability and the environment, because the building industry produces a lot of greenhouse gasses and contributes to the deterioration of the environment. The second cause is the scarcity of raw materials that drives up the prices and it makes countries and Europe as a region vulnerable. The last is possible new employment. It is hard to say how many new jobs are created due to circular economy. However, many articles agree that it will increase. Now it is clear why we as a society should implement circularity, the next chapter will elaborate on the stakeholders in the railway industry.

3 Stakeholders in the Netherlands

So far, the definition of circularity has been clarified and the reasons to implement circularity in an industry is explained. Next up are the stakeholders, the companies and other parties that have interest in the development of a circular railway industry.

3.1 Government/municipality

In the first place the government has great influence on the developments. They can lead companies into the direction they want using laws, goals and subsidies. In the case of circularity it started with the Paris Agreement ("Klimaatakkoord van Parijs") which was signed in 2016. Based on that, the government made plans on carbon neutrality and circularity. In January 2020 Rijkswaterstaat and the Ministry of Infrastructure and Environment have published a report on their strategy to achieve net-zero carbon dioxide emissions and to become circular. They set dates for those goals for the government itself, but for ProRail as well. Rijkswaterstaat has to be circular and carbon neutral in 2030, which corresponds with the Paris Agreement. The Paris Agreement stated as well that Rijkswaterstaat has to cooperate with regional authorities, like municipalities and the provincial governments, to have bigger influence and more power on the import market. They presented their strategy as well, which is based on existing strategy that includes market cooperation, sustainable commissioning, innovation policy and purchasing strategy. To succeed there need to be more cohesion between these things (Ministerie van Infrastructuur en Waterstaat, 2020). These are the most recent plans, but the Ministry of Infrastructures and the Environment has started researching the circular possibilities way earlier. Already in 2013 they instructed TNO to analyze opportunities and obstacles that will occur as the Netherlands moves towards a more circular economy (Bastein et al., 2013). The report includes an action plan for the Dutch government and already notices the importance of using the international playing field to go forward with a circular economy. One of the advises of TNO is that it is rewarding to ensure that frontrunners have a permanent and true advantage to motivate them to innovate towards a circular economy.

On lower level, the municipalities have made their own plans to become a circular economy. They do not necessarily use the same dates as goal for a circular economy. The city of Amsterdam says they aim to move towards a circular economy by 2050 and to halve the use of new raw materials by 2030 (Circle Economy & City of Amsterdam, 2020). The city of Tilburg, on the other hand, is planning on being circular in 2045 (Köper, 2020). However, for this report, the goals and strategy of the government are used, since the railway system interprovincial, so it is better to look on bigger scale. Though for projects like new (circular) stations, this is mostly a collaboration with municipalities.

The Dutch government has great interest in becoming a circular economy, because it has to live up to the agreements that were made in the Paris Agreements and to be prepared for a future with more scarcity of raw materials. This is to have a stronger position in the import market and have more influence. To achieve this a strategy is set up (Ministerie van Infrastructuur en Waterstaat, 2020).

3.2 Nederlandse Spoorwegen (NS)

The state-owned company “Nederlandse Spoorwegen” is the big railway operator in the Netherlands of which the Dutch state has all of the shares. It provides rail services and the infrastructure that is used, which is maintained by ProRail. ProRail will be discussed in section 3.3. NS is one of the 30 transport providers on the Dutch railway system. However, NS is the biggest one in passenger transport. Most of the others are active in freight transport (NS, 2021b).

NS is one of the main stakeholder that will have to execute the plans to actually become circular. They are the ones that have a big responsibility in this case. NS has published that their goal is to purchase only circular products in 2030. Besides that, NS is planning on transforming all relatively small stations into circular stations in 2050. NS is the owner of most of the passenger trains that drive on the Dutch railway system. They provide all of the maintenance and replacements of the trains. Furthermore NS exploits, develops and manages over 400 stations in the Netherlands (NS, 2021b).

NS partly wants to become circular, because they have to keep up a certain reputation. As leading railway company they want to be seen as an innovative and sustainable company. Becoming circular gives this green appearance a boost. This is necessary to be future-proof as well, because sustainable entrepreneurship is the future. On the other hand, there is the financial aspect. As mentioned the prices of raw materials are rising. If they keep rising the company is not profitable anymore. The problem is that circular options are usually pricier and therefore it is a bigger obstacle to become circular (van Oudheusden, 2020).

3.3 ProRail

ProRail manages the railway infrastructure. This job includes the construction, maintenance, management and safety of the railway system in the Netherlands. There are 7000 kilometers of railway track in the Netherlands. ProRail manages the capacity distribution of the trains on the track. This is mainly about passenger transport and freight transport. They are responsible for civil structures (like tunnels and bridges) as well (ProRail, 2021).

ProRail is the other main stakeholder that can make significant changes towards a circular railway system. Several departments of ProRail are working on becoming a circular company. Last February (2021) they organized the ‘Week of Circularity’ (ProRail, 2021). ProRail has the same date as the NS as regards to becoming a carbon neutral and circular company, namely 2050. It is actually more a goal for the railway sector as a whole. Within ProRail, a route map for sustainability is created. This has been made to make sure sustainability is part of every project of ProRail. ProRail actually added sustainability to the mission statement. This means that ProRail finds sustainability and circularity valuable on corporate level as well (K. Nelissen, personal communication, June 2 2021).

Since ProRail is an influential stakeholder, they can help becoming a circular industry. By adjusting their vision on building railways, they can make the contractors they hire build circular.

3.4 Travelers

Travelers are one of the users of the railway network in the Netherlands. For them, there are no personal goals regarding on railway becoming circular, but they put certain pressure on the government and the railway companies on becoming circular and more sustainable. A big part of the population thinks that this is needed to prepare for the future, in which this needs to be the standard.

For the travelers there is a cost perspective as well, since they do not want that the prices of the tickets rise due to the increasing costs of raw materials. This could lead to a decreasing demand of public transportation and that something that the government will definitely want to prevent, since they have put in a lot of effort to stimulate people to use public transportation. That is because public transportation produces less carbon dioxide emissions per person than when everybody uses their own car. It also decreases the amount and length of traffic jams during rush hours. These are all factors that make it more attractive for the travelers to make use of public transportation like the trains. However, in the end it still seems like people have a hard time saying goodbye to their cars.

Travelers can help becoming circular, not only by voting for a certain direction in politics, but also by making sustainable choices in everyday life. The NS tries to stimulate this by making adaptions, especially at the stations. The main focus for travelers is on reducing waste. This is done by promoting the water taps they have installed on 240 stations across the whole county. Another focus point is on the coffee and tea cups. Every year over 30 million cups of coffee and thee are sold on NS stations. To reduce waste, travelers get a discount if they bring their own cup (NS, 2021a). This is of course an extra intriguing concept for Dutch people.

3.5 Freight transport providers

Four-fifths of the total amount of freight trains in the Netherlands has a foreign destination. So, in this case, international collaboration is essential. The government wants to increase the amount of freight that is transported on the railway system, because it is more sustainable. There even was a temporary subsidy arrangement to stimulate the use of trains (Traimco, 2016). Several big railway companies in freight transport on the Dutch railway system are DB Cargo, Lineas, Captrain and Rotterdam Rail Feeding.

DB Cargo is a German railway company specialized in freight transport. They are focusing on becoming carbon dioxide free (DB Cargo, n.d.). Circularity is not mentioned anywhere. Lineas is a Belgian company and the largest private rail freight operator in Europe. Lineas states that the freight transport will grow by 30% (Lineas, n.d.). This is a significant amount and therefore it is even more interesting to see what kind of measurements can be taken to shift to a circular economy. However, Lineas does not mention anything about circularity either. They focus on railway being already the solution for carbon dioxide reduction, since it is quite a good replacement for freight transport by trucks. On the other hand, not mentioning a need to change something in the railway system is more like a denial of another problem. Captrain and Rotterdam Rail Feeding do not mention anything about circularity or sustainability either.

It looks like becoming circular is not a priority in the freight transport industry. Their main focus of looking green is on the fact that train freight transport has less carbon dioxide emissions than freight transport by trucks. However, becoming circular will have significant benefits for this sector in the future, mainly because of the financial aspect mentioned earlier.

3.6 Conclusion

The stakeholders all have a different perspective on the matter of becoming circular. The government has to be invested, because of the agreements that were made in the Paris Agreement. The NS and ProRail both have programs running. They have to make changes to make their company feasible for the future, where the raw materials will definitely be pricier due to scarcity. Travelers do have interest in this topic. Not only because of the increasing ticket prices if nothing happens, but many people are aware that it is not going well with the environment and changes have to be made to make the earth livable for the next generations. Striking is that the freight transport does not show a lot of interest in becoming circular. Maybe they are working on it behind the scenes. In the end, all parties have to work together to make a circular industry work.

4 Application of Circularity in Other Industries

To get ideas of implementation options of circularity, it is interesting to see how other industries work with it. They might have different perspectives on this, so it can be educational for the application of circularity in railway.

4.1 Building Industry

Since a lot of the used materials are the same, the building industry is an useful industry to look at. As mentioned in chapter 2, concrete and steel are a few of the most polluting production processes of building materials there are, so there is definitely a pressure to reduce this production. From this industry there are a whole lot of people who are aware of the need to transition to a circular economy. A team of Dutch experts wrote a transition agenda for a circular building economy ('Transitieagenda Circulaire Bouweconomy'). The team consists of researchers from universities, contractors, people from the government and municipalities, metal companies and architects. The combination of these team members already is a crucial aspect, because it is only way possible to become a circular economy if there is a collaboration between all of the different parties in an industry. They made a list of requirements to become a circular economy (Nelissen et al., 2018). The most fundamental requirements are:

- A mandatory material passport
- Subsidy for circular business models
- Development of a uniform way of measuring circularity
- International collaboration
- Teach about circularity to create awareness

4.1.1 Circulaire BouwHub

The report states it is easiest to start with new buildings and to expand later on to existing buildings. This creates opportunities for a systematic approach to make a material database (Nelissen et al., 2018). Another example of a great collaboration is the 'Circulaire BouwHub' (circular construction hub) in Amsterdam. This is setup by a supplier of building materials, VolkerWessels, and a demolition contractor, Beelen. The goal of this hub is to offer building materials from a dismantled building, but to provide a workplace to use these materials as well. They also opened a hub in Utrecht, where they create new building materials from scrap wood. The hubs have a central locations, which results in less transport and therefore lower costs and carbon dioxide emissions (BouwCirculair, 2021). What keeps becoming clearer is that the technical aspect of implementing circularity in the economy is not the most critical part, because in every report organisation and communication end up to be one of the pitfalls. There are so many stakeholders that it is hard to collaborate, because all of them have different interests. The report 'Een verkenning naar de potentie van bouwhubs' (An exploration of the potential of construction hubs) recommends to start with a few material flows and not try to include the whole chain instantly. This way clients can gain experience and expand later on (Loeber & Snoek, 2020).

4.1.2 Bridges

In the building industry, an appealing construction for reuse is a bridge. That is because there is quite a wide range of bridges that are qualified for reuse. Many of these constructions are relatively easy to disassemble. Rijkswaterstaat and the municipalities of Rotterdam and Amsterdam created the 'Nationale Bruggenbank' (national bridge bank) which shows an overview of bridges that clients are going to replace soon (Nationale Bruggenbank, n.d.). Note that 'soon' is a relative term, because these kind of projects are planned years in advance. For this initiative to work, it is essential that bridges that will become available are posted on the site as early in the process as possible, because that increases the chances to find a new location for the bridge. That is because bridges are designed for a specific location and project managers need time to research which can be implemented on their site. There is an instruction manual about reusing a bridge from the website. Extremely detailed information is needed for complete an application to make sure the clients know everything there is to know about the bridge. This is information includes (van Offenbeek-Kuipers et al., 2021):

- All of the dimensions of the bridge
- Technical information on:
    - Used materials
    - Residual life
    - Complete overview of current and past damages
    - Current state of components
    - Type and state of connections
- Reusability of the bridge:
    - If it is built out of several segments or one whole part
    - If the components are feasible for transportation
    - If components need replacement

Besides the Nationale Burggenbank there is an initiative of Royal HaskoningDHV that already started in the 1980's. This is called the Bruggenbank and is a provider of soon-to-be available bridges (Bruggenbank, 2019). The reason the National Bruggenbank was institutionalized as well, is that Rijkswaterstaat and the municipalities thought this bank should be ran by the government (Nationale Bruggenbank, n.d.).

Currently, mostly 'smaller' bridges are reused, because it is easier for transport. A great example is the Gevlebrug in Amsterdam. This bridge is shown in Figure 2 and was originally called 'Hefbrug 276'. It was a monumental bridge that was built in 1930 as a connection to Amsterdam Central Station. In 2001 the bridge did not fit in the newly designed 'IJ-oever'. Therefore it was removed and stored. After about 20 years the bridge had gotten a new destination at the Houthavens, in Amsterdam as well. This includes the small bridge keepers building that was once built next to the bridge. Figure 3 shows the new location of the bridge, where it has got its new name: Gevlebrug (Triflex bv, 2020).

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Figure 2 Hefbrug 276 in Amsterdam (Stadsarchief Amsterdam, n.d.)

Figure 3 The Gevlebrug in Amsterdam (Triflex bv, 2020)

4.2 Building materials

The next section will zoom in on the industries of different building materials. The most used building materials like steel, timber and concrete are covered.

4.2.1 Steel

Constructions made of steel have potential to be feasible for reuse, because these are relatively easy to disassemble most of the time. Besides, the industry will definitely feel pressure to become more green, because of the enormous carbon dioxide, sulphur dioxide and dust emissions caused by the steel industry, as mentioned in chapter 2 (Ma et al., 2014). Interesting of this construction material is that used steel keeps the same properties as a new steel product. Therefore the strength and reliability stay the same. Of course, when reusing the steel parts, the quality will have to be checked before or during the disassembling. Many constructions that are planned to be demolished, are not demolished

because the constructions is at its end of life, but because the location gets another destination or the construction does not fit into the surroundings anymore. That means that many of the constructions that get demolished are still in great state and thus can be reused. The new destination can either be in a new construction with the same function or it can get a new function, for example in a infrastructure or as temporarily support (Vic Obdam, 2020).

To make reuse easier, it starts with the design, because a new train of thought needs to become normal. This is designing while keeping in mind that it can be disassembled easily. For steel simple choices are available between a joint that is connected with bolts or welds. Bolts are easier to disassemble and it is a less polluting process than welding and grinding a weld, since less energy is needed. This is a decisive factor, since circularity has a lot to do with sustainability and decrease the amount of polluting carbon dioxide emissions in the air.

4.2.2 Timber

Timber itself is often mentioned as a sustainable solution to the problem of the polluting building industry. That is because the timber that is used, will grow back during the lifetime of a well-designed construction. In contrast to most construction materials this one is renewable instead of finite. The reuse of timber is more of a challenge than the other construction materials. This is because it is an organic material, which is usually has had a treatment to be of purpose on a certain location. Timber can be reused if whole sections can be reused in another construction. This way, the carbon and energy that is stored inside the timber, stays inside. Recycling can be performed by shredding the timber and use it in boards for example. The last and less desirable option is energy recovery. This does not fit exactly in the vision of a circular industry (Hart & Pomponi, 2020). However, some would say that the stored carbon dioxide emissions now return to the atmosphere and that when other trees take this in, the cycle is complete again. On the other hand is this not how the circular industry works. It is based on the idea of reusing a product that has already been produced.

Even though it is difficult for timber, some people made attempts to make it fit in the circular industry. They did not yet succeed completely, but one of the better options is cascading. This increases the lifetime of the wood and the quality decreases relatively slow. It still ends with incineration, but it is based on the idea of ‘material use first, energy use last’ (Arnold et al., 2009). Figure 4 show an example of the potential cascading of pine wood (CRISTESCU et al., 2020).

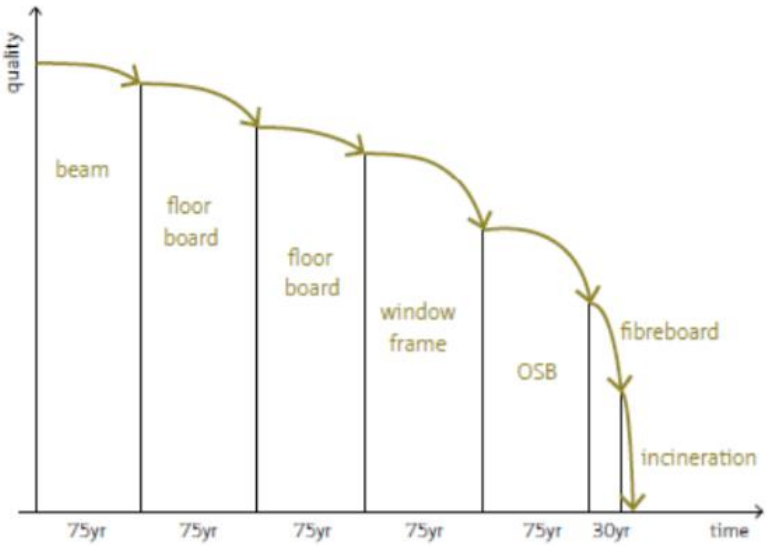

Figure 4 Potential cascading of pinewood (CRISTESCU et al., 2020)

4.2.3 Concrete

As stated before, concrete production is extremely polluting. On the other hand, it can be fit in the circular economy well. On a large scale, concrete demolition waste is already being recycled. The aggregates are used in new concrete or the waste product is used in road construction (Global Cement and Concrete Association, n.d.). It did become clear that circular does not yet have the same definition everywhere, since the term reuse is often being used for this process of recycling. As explained before, reuse would be better. For concrete, especially prefab, reuse is definitely an option. It is relatively easy to design this for disassembly (CEMBUREAU, 2016).

On smaller scale, old concrete slabs are being used for new building. This is with relatively small projects, because it is more of a puzzle to find the right size concrete slabs that fit in the design. Figure 5 shows a house made completely out of reused concrete slabs. This project of the German architect Hervé Biele has got a lot of attention because of it and it is an good step into the direction of a circular building economy (How to Save the World?, 2015).

Figure 5 'Slab house' of reused concrete (How to Save the World?, 2015)

For other specific parts of building there are initiatives as well. For example a hollow-core slab. The technical lifespan of such component is over a 100 years. Often, buildings have a shorter lifespan, so at that time the hollow-core slabs are still in acceptable condition. Again designing for disassembly is a large part of the potential to be reused. A nice example of this in Figure 6. This is a temporary court at the Zuidas in Amsterdam. This building will be disassembled and completely build up in Enschede, where it will have a new function as an office. Unfortunately this is an independent project. The supply and demand for this market does not match yet. Part of this problem is lack of knowledge about the circular building industry. Another part is the costs. Hollow-core slabs are cheap and therefore new slabs are chosen over reused slabs, but this investment has to be made to become circular (De Architect, 2021).

Figure 6 Temporary court in Amsterdam (van Woerkom, 2021)

5 How Circularity Can Be Applied in Railway

To give a clear image on the possible applications of circularity in railway, this section is subdivided in all of the different components of the railway. Some materials, like steel and concrete are useful for the circular economy. Each component is investigated for how it fits in the circular economy. Preferably reused, but otherwise recycled. Some components are explained through an example from practice. Others will be discussed using possible applications.

5.1 Sleepers

Sleepers have had some transformations over the years and new designs keep coming. Traditionally, sleepers are made from timber. Later, sleepers were made from concrete, especially in Europe and Asia. In the Netherlands most tracks have concrete sleepers, though some parts still have sleepers made of timber. In total, the Dutch railway system contains 10 million sleepers and every year 200,000 new sleepers are needed for repairs of new parts of track. Many companies are working on a more sustainable sleeper (ProRail, n.d.-b). Those new sleepers are made from recycled plastics or recycled concrete sleepers (Zasiadko, 2020). A new type is the sulfur concrete sleeper, in which cement is replaced by sulfur. This use of sulfur is advantageous, because less heat, and therefore less energy is needed for the production of this concrete. The temperature that is needed is 140 degrees Celsius instead of 1,400 degrees Celsius. The sulfur makes the concrete sleeper completely recyclable, because it can be molten into a brand new sleepers with the same properties. It also has a longer lifespan, due to a higher resistance to wear and chemical attack. Opportunities to reuse have also been investigated, but since the low melting temperature is it not safe in houses concerning fire resistance. (Geerts, 2021)

Figure 7 'Spoorloper' brug (Welling, 2019)

There are several options for reusing already existing sleepers. Over the years, several design challenges gave opportunities to present these ideas. One of the winning designs was a pedestrian bridge made of a track section on which sleepers were pushed together. The whole section is turned upside down and then forms a bridge (Gompel, 2020). Figure 7 shows an example of this kind of bridge. In this case, a sleeper made of timber is used for

the bridge, but a concrete sleeper could have been used as well. It works the same; the fastening is loosened up, the sleepers are pushed together and tightened again. However, for a bridge like the one in Figure 7 timber looks better in these nature surroundings. Many of those sections with timber sleepers are stored at depositories, because they are replaced with concrete sleepers. At some tracks in the Netherlands there are still timber sleepers. The problem is that when one or two sleepers need replacement, there is no system to replace it with an old timber sleeper from the depository, but a new tree is cut down. This is unnecessary and shows the need for a material databank. However, for timber it is harder to check the quality of the sleepers is reuse is wanted compared to concrete.

Another opportunity is for the twin block sleepers. These sleepers have two supports made of concrete that are connected with a steel bar. One of the pioneers of the circular building industry, Voestalpine Railpro, states that these sleepers could be used as pillars or in the foundation. From standard concrete sleepers they also made couches at stations (Gompel, 2020).

5.2 Ballast and concrete slab

Standard ballast materials for railway tracks are sharp-edged rocks and aggregates. The sharp-edges property is essential for the ballast to be stable. The ballast layer also provides good drainage. Over time, due to loading of the ballast, the aggregates become more round-shaped. Therefore, they lose their stability and the ballast does not provide a stable base for the track (REMEX, n.d.). This is the moment they are removed and recycled or reused.

In the railway industry, several option already exist to reuse ballast material. However, how much can be reused depends on the state of the material. The first option is to remove the ballast material that does not suffice anymore and replace it with new ‘recycled’ ballast material. The removed ballast material is then transported by train or truck to the processing plant. Then it will be cleaned and special machines make sure it is sharp-edged again (REMEX, n.d.). This material is not necessarily immediately usable as new ballast material, because the grading of the material needs to be checked. Research show that this ‘recycled’ material often has not yet got the right grading. It is frequently way off. That is because of wear of the ballast material, which produces a lot of fine material and aggregates with a smaller diameter. Aggregates of a bigger size (63 mm) are missing from the material (Tangerås, 2019). Note that ‘recycled’ is not a fitting term in this case, since the process is more of a touch up. However, most companies call this recycling in their processes. After getting the right gradation in the mix, the ballast material is ready to be reused.

Not all of the ballast is suitable for reuse. Part of the retrieved material ends up in road construction. Especially fine graded aggregates are suitable for reuse in road construction. In this case, particles smaller than 30 mm are included as fine graded aggregates. The reuse that is mentioned in the previous section is of course preferable, but this is a good alternative to reduce the waste pile (Mirzababaei et al., 2018).

Another option to reuse the ballast material is by using the PM 1000 URM, which is a train of 1,2 kilometres long. This gigantic train removes, filters, cleans and relocates ballast material from different ballast layers all at the same time on the train. The train moves extremely slowly of course (120 m/h), but an attractive aspect of this technique is that track does not have to be removed and the whole process takes place on track (ProRail, 2011).

Instead of a standard ballast layer made of aggregates, the engineer can also choose for a concrete slab track. An example of this application is the 'Hogesnelheidlijn' (HSL), which means high speed track. The HSL is a track from Schiphol airport in Amsterdam to Antwerp in Belgium. The advantages of using a concrete slab are durability and relatively little maintenance. The expected lifespan of the concrete slab used for the HSL is 100 years. However, if for some reason this is not reached, the concrete could be reused. For example in a way that is explained in section 4.2.3 (Kuijpers & Schwanen, n.d.).

5.3 Civil structures

With civil structures, bridges and tunnels are meant. Bridges can definitely be reused. Sometimes as a whole, sometimes parts of it. Initiatives like a database for bridges that will become available for reuse are further explained in section 4.1.2. In this section, it is not explained precisely for bridges that are used for trains, but this could go exactly the same. In the Netherlands, bridges are mostly used as a means to pass a waterway. However, tunnels are used as well. Bridges were already a challenge to implement on a new location, but for tunnels the challenge is even more difficult, because it is underground or underwater.

For immersed tunnels, research has shown that those tunnels can indeed be reused. This is done by re-floating the tunnels temporarily. Requirements to do this are the right amount of tunnel elements (3 - 10 elements), using prefab concrete and preferably a removable bulkhead. All of these points reduce the chances of leaking, which can be catastrophic to the project. This research was originally performed to see if it is possible able to make the waterways deeper for bigger cargo ships. The tunnel would be re-floated and placed back deeper (de Jong, 2020). Relocating the whole tunnel would be a way bigger challenge of course, both technical as organizational, because this project will be extra sensitive to failure. Also, the tunnels are made for a specific location and will therefore not fit precisely at the new location. Adjustments will have to be made to make this fit.

5.4 In and around the stations

The NS exploits, develops and manages over 400 stations in the Netherlands. As mentioned in section 3.2, the goal of NS, ProRail and Bureau Spoorbouwmeester is to have made all stations completely circular in 2050. Together they started the What If Lab, which is a contest where design plans for circular stations are presented by the participants. Four designs were chosen and all have fascinating ideas to make circular station. The requirements for the contest were: prevent waste and there needed to be reuse of existing buildings, products and/or materials (van der Wel, 2020).

A station itself has many components as well. All the four design teams focused on something else. The first design is called the Bio receptive Station. For this design the engineers focused on making the railway infrastructure contribute to a more sustainable design. Using recycled sleepers they created sound barriers with mosses and algae that absorb carbon dioxide. This way the barriers have a double function at which they contribute to a more circular station. Besides that, they also reduce the maintenance cost and are anti-graffiti. Figure 8 shows this design (Scape Agency, n.d.). The second design changes the way stations are designed completely. They approach it from the service a stations provides. This way they could integrate the design completely in the nature. This resulted in The Natural Station, a station that is integrated in a park. This is an interesting way of designing. However, this would not fit everywhere and misses several facilities that people appreciate at a station. For example small supermarkets or coffee shops for when people have a long transfer time (Leonie Welling, n.d.). The third concept from the challenge is more of an idea

on how to start designing. This plan is based on collaboration with local parties and to let them participate in the process of becoming circular. This gives the opportunity to use local materials instead of transporting them from the other side of the country (Bygg Architecture & Design, n.d.). The last design is intriguing, because it is more a plan for the whole station. This design is based on the knowledge that ProRail owns a lot of land around the tracks and on this land grow plants that can serve as renewable raw material. One of the ideas is to replace part of the concrete that is used on the stations, because this is not a sustainable material. Besides that, concrete is now being used for things like furniture that absolutely do not need that kind of strength. After extensive research, one of the better replacements were mussel shells from Zeeland. The reed plant ended up to be a good option to strengthen walls to insulate them, which reduces the amount of concrete that is used on the stations (Studio Tjeerd van Veenhoven, n.d.).

Figure 8 Green sound barriers (Scape Agency, n.d.)

NS is also stimulating the reduce of waste on the stations. One of the initiatives is to promote to bring your own cup for coffee or tea instead of using a disposable cup. People even get a discount if they do so. This seems small at first sight. However, when looking at the numbers, it is clear that this can have real impact on the waste at the stations, because every year over 30 million cups of coffee or tea are consumed. Another initiative are water taps that are installed at over 200 stations in the Netherlands. Here, travellers can get drinking water for free. The water taps are located in a way that 90% of the travellers go past a water tap on their route. This initiative stimulates people to use refillable water bottles instead of disposable ones (NS, 2021a).

On smaller scale, several stations are getting circular elements as well. For example, by replacing all of the tiles of the platforms by tiles from another stations that are 100% recycled. Due to the high groundwater level in the Netherlands, many retaining walls are needed. These retaining walls can be made from recycled concrete and they are designed for reduce of material long term, because their height can be adjusted while they stay in place. Otherwise the whole station would have to be excavated to replace them. This does not only reduce the amount of energy that has to be used, but the amount of concrete as well, because otherwise new concrete retaining walls had to be installed (ProRail, n.d.-a).

Another example of circular use in the railway industry is the reuse of noise barriers. This is a project from ProRail, where they reused noise barriers made of glass from the HSL at

another track. There was nothing wrong with these barriers, but the concrete slab that was used at the HSL the sound waves were reflected differently than normal and therefore different sound barriers were needed. That means they are perfect for reuse at another track with traditional sleepers. However, this project is not that easy, because glass is a fragile material and therefore the disassembling and transport costs more money and time. On the other hand, there were no direct material costs, since the barriers were sort of free (P. Mooij, personal communication, May 18 2021).

5.5 Train

For the train itself are many possibilities for reuse and recycling as well. This is because of the many components the trains consists of. In the Netherlands, the NS is responsible for the maintenance of the trains. One of the most common models is the VIRM train, which is a double-decker train and is also known as an Intercity train. After the first 20 years of service the trains get a touch up. 86% of the components will be fixed and 13% will be reused somewhere else. By performing the maintenance this way, 25 million kilos of materials stay in circulation and the train can drive again for 20 more years. Again after 20 years the trains are checked. Part of the trains can go back on the track after they are fixed again and the other part is getting a second life somewhere else. This can be for a museum, the fire brigade or the train will be disassembled and the valuable components are getting reused (NS, 2021a).

This reuse can be in new trains, but some parts can also be used for new products that are completely different. In these cases value is added to the product and is therefore upcycled. Some examples of this are; bags made of train seat fabric, ping-pong tables and other furniture made of train floors, design speaker made of broadcast speakers and many others (NS, n.d.). This way materials that are already being used in trains get a second life.

Another option is trying to increase the amount of sustainable materials that are used in the production of trains. Or use more mono-products, products that consist only one kind of material, because they are easier to recycle. For example, the sidewalls of a train could become completely circular. Research from a graduation student at the TU Delft shows that this can be achieved using a honeycomb panel. The sidewall panels are designed for reuse and fit therefore in the circular economy (van Oudheusden, 2020). Another example are sleepers made from train components, like the side walls and luggage racks. These are made from lightweight plastics and ended up to be perfect for sleepers (van der Wel, 2021). These are of course only a few examples, but many more aspects of the train can be designed differently to reduce the amount of raw materials that is needed and to make it easier to reuse.

5.6 Track

The railway track does fit well in the circular plans as well. The steel rails of old tracks can be reused on new tracks. If for some reason it is not fit for high speed passing, it could also be reused at a train depot. Removing it from the former location is relatively easy, because the rail always consists of components that are welded together. They can be over 150 meters long, so transport is not trouble-free. However, this is not any different than when new rails of this length have to be transported. One of the possible difficulties can occur when putting it all together. This happened to BAM Infra when they were working on a completely circular train depot in Arnhem. The head of the rails was worn differently on the different parts of the rails that needed to be welded together. These kind of setbacks can cause a lot of delay, but this is going to stay part of circularity in building industries, because

materials that have been used before are in a different state and shape than new ones (M. Bruines, personal communication, June 2 2021).

The track can be interpreted as the actual rails, but also as the track itself. For example an elevated rail line. In New York they made a park of an old elevated rail line. This track goes straight through the city and was used by freight trains until the 1980's. At first the plan was to demolish it, but fast arose a plan to make a recreational area out of it. In 2009 the park opened. It has a lot of green and gives opportunity to show art. This project, that is called The High Line, is a great example of reusing a large structure, giving it a new function and prevent a lot of waste. It is sustainable, especially in combination with the 110,000 plants that are placed on the elevated rail line (The High Line, 2019). Figure 9 shows the High Line park through Manhattan, New York.

Figure 9 The Highline, New York (Baan, 2011)

5.7 Switches

Switches are a crucial part of the railway track, since they are the moving parts of the tracks and they have to operate in harsh conditions. Therefore, the switches have high maintenance demands and more equipment is needed for the building phase. All of this

leads to a need to reduce the amount of new switches that is made. Especially since switches that are written of still contain valuable parts that can be reused. The process of reusing switches goes as follows: first, the switches will be disassembled and cleaned, because a lot of filth can gather at the switches. To check the condition of the different parts of the switches, a non-destructive test will be performed. Some parts will have to be removed if they are really unusable. Next is overlay welding. A new layer with a higher wear resistance is added. And finally after new non-destructive tests, the new switches can be installed (Dendrit, n.d.).

At the train depot in Arnhem mentioned before, circular switches were used as well. Though, critical is that the quality of the switches is high. That is because safety is one of the most crucial subjects in the railway industry and switches play a significant role. The goal needs to be to find a balance between safety, costs and sustainability, because switches are the components of the track with one of the highest environmental impact (Landgraf & Marschnig, 2019).

In the Netherlands, the main railway companies are already reusing switches if possible. This reduces the transport that is needed, but also reduces the carbon dioxide emissions, because less switches have to be produced and the transport is shorter, since the contractor will already have them in storage.

5.8 Fastening system

The fastening system fixes the rail to the sleepers. There are various types of fastening systems for trains. Partly this is depending on the type of sleepers, but most of the time the basics are the same. The fastening system exists of the fastenings, the plats, the pads and the screws. These products are made of different materials and therefore is the fastening system not always reusable as a whole. Figure 10 shows the different parts of the fastening system.

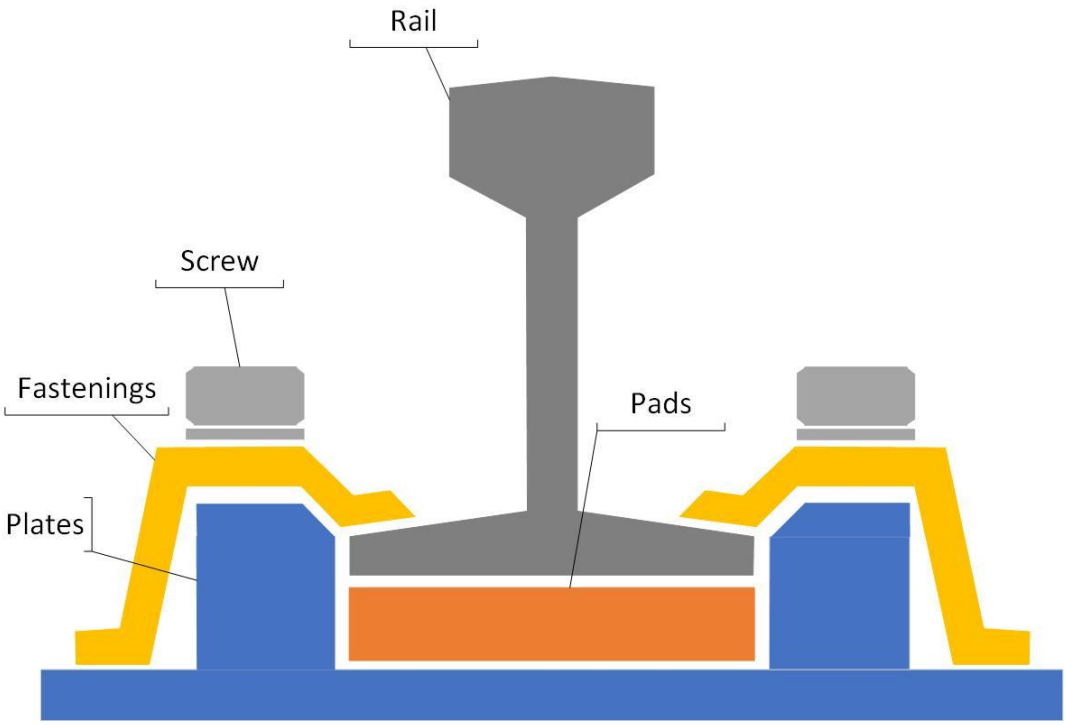

Figure 10 Schematic rail fastening system (J.Kloet, 2021)

First the pads. These rail pads are made from rubber and have an area of about 10x10cm. Their function is to reduce the vibrations caused by passing trains. The pads have to withstand gigantic forces caused by passing trains. Figure 11 is a great example of the destruction of the pads due to the applied forces. This shows that the rail pads are not directly usable for reuse. However, recycling is a good option. The rail pads can be made from recycled materials that are seen as waste, like used tires (Jayasuriya et al., 2020).

Figure 11 Rail pads in different states of decay (MOOC - TU Delft, 2021)

The screws can be reused sometimes. This depends on whether or not they have ever reached the yielding point. In theory, the screws that have not reached the yielding point can be reused (Bossard, 2014). The question if it is manageable to check every screw and note this in a material database. This probably is not. Anyway not in this stadium of becoming a circular industry. Maybe this will economically be interesting once everything is organized better. For now recycling is a better option for the screws.

The base plates are on the bottom of the fastening system. They keep the rails in place, together with the fastenings. These parts are made of steel. Again, if the products can be reused depends on the state of the products. Non-destructive could determine the state and can help decide if reuse is fit for reuse. Reuse would be best, since steel has a high environmental impact.

5.10 Organization

In the end circularity succeeds or fails with organization. Even if all the reuse possibilities are available, it needs to be organized where the materials are available and how the transport will go. It all starts with a material passport and a database with all of the information. ProRail has set this up within its own company, but it is not yet widely used (K. Nelissen, personal communication, June 2 2021). Other companies like the contractor BAM is setting this up as well (M. Bruines, personal communication, June 2 2021). However, this is still a challenge, because it is not feasible to include all products at the same time. This is an immense job to do. Therefore it is smart to start with a selection of products first and to see how these can be reused within the company. If this works, the selection could be expanded and the database could be shared with other companies. For example with all railway related companies in the Netherlands. This can reduce the transport if products are available closer to the building site.

To achieve all of this, the mindset in the companies has to be changed. This is quite a challenge, because the companies that are active in the railway industry have always strived to avoid risks as much as possible and to go for optimal safety and punctuality. The wish to become circular therefore has to be in the top of the companies as well as in the project teams. Companies can try to realize this by setting up a circularity team who are going to

spread the word on how to implement circularity in the projects. However, even if this succeeds, the client has to have the same goals, because circularity is not particularly cheap. Sustainability can cost money, because in the current state of the process a lot of extra effort, time and work has to be put in the project to make it circular. Part of the problem is also the old guidelines provided by the companies themselves. Those guidelines state that some parts have to be made out of concrete, but this does not always fit in the circular mindset anymore. The guidelines could be improved by including the functions and needed lifespans of the products instead of the specific materials that need to be used (K. Nelissen, personal communication, June 2 2021).

The railway industry has a high environmental impact due to the materials and machines that are used. As mentioned many times before reduce, reuse and recycling are of the essence. This is not something everyone in the project teams is familiar with. Some might be experts in concrete or steel. In some cases these people will need to be retrained in the use of reused or recycled materials, because these materials will not have the standard dimensions or quality they are used to work with when the materials come directly from the factory. It is not only about reducing the use of raw materials, but about the reduce of energy as well. For the production, transport and maintenance many times heavy duty is used. The goal will be to reduce emissions and to use green energy as much as possible. Modular design is also one of the options that could be explored. This way, only the components that are broken have to be replaced instead of the whole part. This is as designing for disassembling, which will reduce costs and energy at the end of the lifespan.

Finally, to be successful in the implementation of circularity in railway companies will have to listen to new and innovative voices. This starts at the university. Since circularity is new, it is not yet a part of the education. It is of interest that this will be changed, because in the world after university this is a big topic. Same goes for sustainability. These topics are not or only slightly covered during the education for engineers. For the future, this change is essential to make it work.

5.11 Overview of applications

Table 1 gives an overview of the discussed application of circularity in railway.

Tabel 1 Overview of possible applications of circularity in railway

Main component	Component/Material	Next life?
Sleepers	Timber	**Reuse** is possible as sleeper, but depending on the state of the sleeper
		Reuse is possible as pedestrian bridge
	Concrete	**Reuse** is possible as sleeper or in the building industry
		New concrete sleepers can be designed using sulfur which are better to **reuse** and **recycle**
		Twin block sleepers can be **reused** in building industry as pillars or in the foundation
		Reuse is possible as furniture on stations. For example, a couch
Ballast / Concrete slab	Ballast	**Reuse** is possible after making it sharp-edged again, clean it and rearrange the grading on a special processing plant or with a special train
		Reuse is possible in road construction if the quality is not high enough for train ballast

Main Component	Component/Material	Next life?
	Concrete slab	A concrete slab is more durable than ballast material in form of aggregates (design for **reduce**)
		Reuse is possible in the building industry as wall for example
Civil structures	Bridge	**Reuse** is possible as a whole or per component
	Tunnel	**Reuse** is complex, but possible by re-floating. However, this process is extremely sensitive for errors
In and around stations	Concrete noise barriers	New design with **recycled** sleepers and mosses and algae that absorb carbon dioxide
	Glass noise barriers	**Reuse** is possible at a different location
		Recycled is possible by melting it into something different
	Complete station	Using local resources to **recycle** materials
	Furniture	**Reduce** use of concrete by using more sustainable materials, like mussel shells and reed plants
	Cups/water bottles	Promote using non-disposable cups and water bottles by giving discounts and placing water taps to **reduce** waste
	Platform tiles	**Reused** or **recycling** completely is depending on the state
Train		Can be **reused** in museum, fire brigade or be disassembled and parts can be reused in other trains
		Parts can be **upcycled** by making bags of rain seat fabric, ping-pong tables and other furniture made of train floors, design speaker made of broadcast speakers
		Designing with **reduce** in mind, is possible by replacing some steel and plastic components by honeycomb panels made of some sort of cardboard
		Recycling side walls and luggage racks and use them for sleepers
Track		Complete **reuse** is possible if the steel is in still of the right quality
		An elevated track is also **reusable**, especially in the city, where it could be transformed in a park or get another destination
Switches		Complete **reuse** is possible, but depending on the state. Otherwise parts can be reused
Fastening system	Pads	Can be made from **recycled** rubber tiles
		Reuse is hard because of the wear
	Screws	**Reuse** is possible in theory, however, it costs too much effort and money to reuse these yet
		Recycling is possible by melting the steel
	Base plates	**Reuse** is possible, but depending on the state.
		Recycling is possible by melting the steel.

6 Conclusion

The goal of this report was to answer the research question; How can circularity be applied in railway? This problem does not have one perfect solution. This is caused by several factors. The first one is the definition of circularity, reuse and recycling. The definitions are interpreted and used different by several companies and therefore it is harder to compare the solutions. The second one is the complexity of the adjustments, because the mindset and way of working of whole companies have to be adjusted.

The answer to the research question consists of two main components. The first one includes the technical challenges. For all of the parts of the railway industry possibilities for reduce, reuse and recycling have to be explored. For the sleepers and the ballast, for example, already good initiatives exist that can be used on a bigger scale, but for the industry as a whole, this research is still in the starting phase. The second component is the organizational challenge. Entire companies have to change their way of working. Especially since the designing in this industry is traditionally based on striving for low risks and maximum safety. Those are things that do not go hand in hand with the transformation into a circular industry. Therefore, big changes within the companies are necessary to achieve the goals of becoming completely circular in 2050.

7 Discussion

This report shows that the transition into a circular railway industry is complex. It will take a lot of time before the full transition is completed. To succeed, the right people are needed in the right places to persuade the people with power that changes are needed to achieve the set goals. The technical capacity is already there, but more research has to be done and used well.

One of the limitations of this research was the amount of time. It is a big subject and therefore is it impossible to address all of the points that could be considered. That also results in an answer to the research question that is not as complete as it could be. In addition, it is not possible to present one single solution for this problem. It all depends on interpretation and the mentality of the companies with the most influence in this industry. Another limitation was the newness of the subject. Some stakeholders started setting up circular programs only this year. Therefore, not that much research has yet been done and many of the given solutions are examples of applications of circularity. However, this does not mean these are the only options. There are probably way more, but these options still have to be explored. From these facts could be concluded that the report is incomplete, but another perspective is that this is just the beginning of an fascinating transition into a circular railway industry.

For a follow-up research report, more applications of circularity could be explored. This is necessary, because the plans to become completely circular demand extensive research on the possibilities. One of the main focus points should be setting a big material database. This way, every railway company in the Netherlands can see which materials are available and at which location, because this will be a big step in the transition.

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