20-7-2023

WORKING RULES IN DESIGN PROCESSES ON DEVELOPING CIRCULAR SOLUTIONS

MSc Thesis report

TIM STEVERING

anteagroup

UNIVERSITY OF TWENTE.

Colophon

Technical information:	
Report type:	Master Thesis Report
Title:	Working rules in design processes on developing circular solutions
Date:	20-07-2023
Place:	Enschede, Overijssel
Author information:	
Author:	Tim Stevering
Study:	Master Construction Management & Engineering
Institution:	The University of Twente

Executive summary

Introduction

A circular economy aims to reduce the introduction of virgin materials as much as possible by keeping existing materials in the loop for longer. This aids in the reduction of multiple societal challenges such as climate change, biodiversity loss and resource scarcity. The construction sector has a major impact on the material consumption in the Netherlands as it consumes 50% of the virgin materials (Dutch Ministry of Infrastructure and Water Management, 2016) and produces 33% of the waste in the country (Hanemaaijer, Kishna, Koch, Prins, & Wilting, 2021). Antea Group intends to take social responsibility by committing to increase the importance of circularity in their projects. Currently, too few projects are being completed at the infrastructure department of Antea Group in which circularity plays a substantial role. The concept of circularity remains underemphasized in projects. Something is seemingly hindering the use of circular principles in working processes. The goal of this research project is to identify the working rules within design teams, how these rules affect the implementation of circularity and recommend alterations to these rules to improve the incorporation of circularity in design projects.

Method

The Institutional Analysis and Development (IAD) framework (Ostrom, 2005) has been used to identify the working rules that affect the decision-making between different positions in the project team and can be used to link these rules to the development of circular solutions. Three cases in which a level railroad crossing was replaced with a railroad underpass were analysed. The main difference between the cases is the way circularity is implemented. In NABO Almen, circularity is implemented by an ECI calculation at the end. In the three NABOs of the municipality Hof van Twente (HvT), a circular brainstorm session was held during the design phase and for the N631, circularity was included from the start with an Ambitionweb session early on. For the analysis, ten semi-structured interviews were held with multiple different positions in the project teams as well as a detailed document analysis.

Results

Eighteen working rules could be identified across the seven distinct categories in the IAD framework. Figures 13, 14 & 15 show how and in what phase of the process these working rules contribute to the development of circular solutions. Most rules recurred in each case project. Interestingly, these cases showed that circularity in the process is set up as a side process and that the sustainability consultant is the only one working on it. Furthermore, Antea Group adopts a wait-and-see attitude regarding circularity in which it only incorporates it into the project if the client specifically demands it. As a result, circularity may not be brought up as a requirement until late in the design phase, which happened in Almen and HvT. As the designs were almost finished, the design freedom to incorporate circularity was limited. In the N631 case, the sustainability consultant held an Ambitionweb session in which circular opportunities were explored and discussed, resulting in a memo with these opportunities. However, that is where the involvement of the sustainability consultant ended due to the lack of further lead time and budget included in the scope to keep him on board. As he was the only position in this project with a focus on circularity, the importance of the criterion decreased when he left the project team. Subsequently, no concrete decisions on what opportunities to pursue were taken. Resulting in no specific opportunities to be included in the System Requirement Specification (SRS). Only some vague circular requirements were included. As the design is based on the SRS, the design team did not know how to implement the vague circular requirements. Combined with the fact that circularity is perceived to be less important than other criteria such as time, budget, railroad availability and safety, it made it less of an issue to marginalise the circular requirements. As the N631 project was complex, the circular ambitions were marginalised. Resulting in fewer circular results than expected based on the Ambitionweb session.

Discussion

The results show a reliance on the sustainability expert for circular knowledge. The level of circular knowledge with the other interviewees ranged from little to no knowledge and experience with it to a substantial knowledge of the principle but no specific know-how on how to incorporate it in the tasks connected to their specific positions in the project team. This is supported by literature (Hart, Adams, Giesekam, Tingley, & Pomponi, 2019; Coenen, Volker, & Visscher, 2022; Eberhardt, Birkved, & Birgisdottir, 2022). Subsequently, the focus on circularity disappears as soon as the sustainability consultant leaves the project. Circularity is, furthermore, regarded as a *Nice-to-have* criterion and not a core requirement, meaning it is implemented as long as it does not compromise other criteria. This also is supported by Coenen, Volker & Visscher (2022).

Recommendations

The main recommendation is to provide existing positions with a circular responsibility and the know-how and tools to include circularity in their position-specific tasks.

In the initiation phase, the wait-and-see approach should be altered to a more active incorporation of circularity in the initiation phase by discussing the circular ambition of the client. The project leader seems to be in the position to do so as he has the client contact in this phase and is responsible for setting the scope, budget and schedule of the project. To enable him to do so, he should be educated on Antea Groups' possibilities to include circularity in a project and how to properly include them in the scope of the project.

During the conditioning research phase, circular ambitions should be specified and circular opportunities should be investigated. Conducting an Ambitionweb session early on in this phase specifies the circular ambitions and enables the positions involved to specifically investigate opportunities connected to the ambitions. Another session should be held later in which the client/ stakeholders choose what opportunities to pursue in the design. These opportunities need to be specified as requirements in the SRS. These requirements should be SMART to properly integrate them into the design and verify them. The contract consultant, therefore, should be educated on how to make these requirements SMART.

In the design phase, the design team should be provided with the tools and know-how to make the circular impact tangible while designing. Currently, the circular impact is only assessed after the design is finished using an ECI calculation. Tools that can be used to provide real-time circular indications could include rules-of-thumb or real-time circular score indicators within design software. Further research on how to properly introduce these tools is recommended as already tools such as the circular design principles (Dutch Ministry of Infrastructure and Water Management, 2020) have been introduced but are scarcely used.

Concluding, it is recommended to broaden the role of circularity in the process by integrating circular tasks with specific positions rather than placing it solely with the sustainability consultant. By applying the recommendations above, there would be an earlier focus on circularity ensuring it to be accounted for in the project scope. Circular requirements can be better incorporated in the design phase and properly verified when they are described in the SRS in a SMART manner. Finally, it should be taken into account that circularity is only one of the ambitions within the overarching theme of sustainability. Each project has specific ambitions but this standardised approach should provide enough flexibility to ensure these ambitions can be met.

Samenvatting

Inleiding

Een circulaire economie is erop gericht om het gebruik van nieuwe materialen zoveel mogelijk te beperken door bestaande materialen langer in de kringloop te houden. Dit draagt bij aan het verminderen van meerdere maatschappelijke uitdagingen zoals klimaatverandering, verlies van biodiversiteit en grondstoffen schaarste. De bouw heeft een substantiële invloed op het materiaalverbruik in Nederland omdat het 50% van alle nieuwe materialen gebruikt (Dutch Ministry of Infrastructure and Water Management, 2016) en 33% van het afval produceert (Hanemaaijer, Kishna, Koch, Prins, & Wilting, 2021). Antea Group wil zijn maatschappelijke verantwoordelijkheid nemen door het belang van circulariteit binnen hun projecten te vergroten. Circulariteit blijft onderbelicht in de huidige projecten. Iets lijkt het gebruik van circulaire principes tijdens het werk in projecten bij de businesslijn Infra te bemoeilijken. Dit onderzoek heeft als doel om de werkregels binnen projectteams te identificeren, onderzoeken hoe deze het implementeren van circulariteit beïnvloeden en aanbevelingen te doen om de incorporatie van circulariteit in ontwerpprojecten te verbeteren.

Methode

Het Institutional Analysis and Development (IAD) raamwerk (Ostrom, 2005) is gebruikt om werkregels met betrekking tot het toepassen van circulariteit binnen projecten te identificeren. Hiervoor zijn drie casussen waarin een gelijkvloerse spoorwegovergang werd vervangen door een spoorwegonderdoorgang geanalyseerd. Het voornaamste verschil tussen de casussen is de manier waarop circulariteit verworven zat in het proces. In de NABO Almen is circulariteit meegenomen door een MKI-berekening uit te laten voeren aan het eind van het proces. In de drie NABOs van de gemeente Hof van Twente (HvT) is tijdens de ontwerpfase een circulaire brainstormsessie gehouden. Voor de N631 is circulariteit vanaf het begin meegenomen in het proces door vroegtijdig een Ambitiewebsessie te houden. Voor de analyse zijn tien semigestructureerde interviews afgenomen met verschillende functies binnen de projectteams, evenals een gedetailleerde documentenanalyse.

Resultaten

Achttien werkregels zijn gevonden binnen de zeven verschillende categorieën van het IAD-raamwerk. Figuren 13, 14 en 15 laten zien hoe, en in welke fase van het proces deze werkregels bijdragen aan het ontwikkelen van circulaire oplossingen. Het grootste deel van de regels kwamen in alle drie de casussen voor. Opmerkelijk is dat de casussen lieten zien dat circulariteit binnen het proces opgezet is als een zijproces en dat de adviseur duurzaamheid de enige persoon is die zich ermee bezighoudt. Daarnaast neemt Antea Group een afwachtende houding aan tegen de opdrachtgever ten aanzien van circulariteit. Het wordt enkel meegenomen als de opdrachtgever er specifiek naar vraagt. Hierdoor kan het voorkomen dat circulariteit pas laat in het proces ter sprake komt zoals bij Almen en HvT het geval was. Omdat de ontwerpen bijna af waren, was de ontwerpvrijheid om circulariteit te kunnen integreren beperkt. Voor de N631 hield de adviseur duurzaamheid een Ambitiewebsessie waarin circulaire kansen werden verkend en besproken. Dit resulteerde in een memo met kansen. Daar eindigde echter de betrokkenheid van de adviseur duurzaamheid omdat er in de scope geen verdere tijd en budget was gereserveerd om hem aan boord te houden. Omdat hij de kennisdrager op het gebied van circulariteit binnen het projectteam was, nam het belang van dit criterium af nadat hij vertrok. Hierdoor werden er geen concrete besluiten genomen over op welke kansen zou worden doorgepakt. Met als gevolg dat er geen concrete eisen werden opgenomen in de systeem eisen specificatie (SRS). Er werden enkel wat vage circulaire eisen opgenomen. Aangezien het ontwerpteam een ontwerp maakt op basis van de SRS, is het lastig om de vage circulaire eisen toe te passen in het ontwerp. Dit, gecombineerd met het feit dat circulariteit als minder belangrijk wordt ervaren als andere criteria zoals tijd, geld, beschikbaarheid

van het spoor en veiligheid, zorgde ervoor dat de circulaire eisen beperkt toegepast werden. Resulterend in een lagere circulaire impact dan verwacht op basis van de Ambitiewebsessie.

Discussie

De resultaten tonen dat het projectteam afhankelijk is van de adviseur duurzaamheid voor circulaire kennis. Het niveau circulaire kennis bij de andere geïnterviewden varieerde van weinig kennis en ervaring tot een substantiële kennis van het principe maar geen specifieke vakkennis om het binnen hun eigen specialisatie toe te kunnen passen. Dit wordt ook aangeduid in literatuur (Hart, Adams, Giesekam, Tingley, & Pomponi, 2019; Coenen, Volker, & Visscher, 2022; Eberhardt, Birkved, & Birgisdottir, 2022). Hierdoor verdwijnt de focus op circulariteit zodra de adviseur duurzaamheid niet bij het project betrokken is of het project heeft verlaten. Circulariteit wordt bovendien beschouwd als een *Nice-to-have* criterium en niet als kernvereiste, waardoor het veelal enkel wordt geïmplementeerd als dat niet ten koste gaat van andere criteria. Coenen, Volker & Visscher (2022) ziet dit ook terug.

Aanbevelingen

De belangrijkste aanbeveling is om specifieke functies te voorzien van een circulaire verantwoordelijkheid en de vakkennis en hulpmiddelen om circulariteit op te nemen in hun functie specifieke taken. In de initiatiefase moet het gesprek met de opdrachtgever over circulaire ambities aan worden gegaan door de projectleider. Hij heeft immers het klantcontact en bepaald met hen de scope, budget en planning van het project. Hiervoor moet hij worden voorgelicht over de mogelijkheden binnen Antea Group om circulariteit in een project op te nemen en hoe hij dit op een juiste manier in de scope van het project kan opnemen.

Tijdens de conditionerende onderzoeken en de systems engineering fase moeten circulaire ambities worden gespecificeerd en circulaire kansen worden onderzocht. Door vroeg in deze fase een Ambitiewebsessie te houden worden de circulaire ambities gespecificeerd en kunnen de betrokken posities gerichter kansen onderzoeken die verbonden zijn aan deze ambities. Later moet er nog een sessie gehouden worden waarin de opdrachtgever/stakeholders kiezen welke kansen nagestreefd moeten worden in het ontwerp. Deze kansen moeten worden gespecificeerd als eisen in de SRS. Deze eisen moeten SMART zijn om ze goed in het ontwerp te kunnen integreren en verifiëren. De contractadviseur moet daarom leren hoe hij deze eisen SMART kan maken.

In de ontwerpfase moet het ontwerpteam worden voorzien van de hulpmiddelen en vakkennis om de circulaire impact tastbaar te maken tijdens het ontwerpen. Nu wordt er enkel aan het eind van een ontwerp een MKI-score bepaald. Hulpmiddelen die tijdens het ontwerp circulariteit tastbaar kunnen maken zijn bijvoorbeeld circulaire vuistregels of een real-time circulaire score indicator binnen ontwerpsoftware. Verder onderzoek moet worden gedaan naar een geschikte manier om deze hulpmiddelen te introduceren, aangezien er al hulpmiddelen beschikbaar zijn (zoals de circulaire ontwerpprincipes (Dutch Ministry of Infrastructure and Water Management, 2020) maar nauwelijks worden toegepast.

Concluderend wordt er aanbevolen om de rol van circulariteit in het proces te verbreden door circulaire taken toe te voegen aan de bestaande takensets van verschillende functies in plaats van enkel de adviseur duurzaamheid naar circulariteit te laten kijken. Bovenstaande aanbevelingen vergoten de aandacht voor circulariteit door er eerder bij stil te staan en het dus mee te nemen in de projectscope en circulaire eisen kunnen beter worden opgenomen in de ontwerpfase als zij SMART worden beschreven in de SRS. Tot slot dient men er rekening mee te houden dat circulariteit slechts een van de ambities is binnen het overkoepelende thema duurzaamheid. In ieder project spelen specifieke ambities, maar deze gestandaardiseerde aanpak moet voldoende flexibiliteit bieden om aan al deze ambities te kunnen voldoen.

Table of contents

Table of Figures

Table of Tables

Acronyms

Acronyms	Term	Dutch translation
AG	Antea Group	-
ECI	Environmental Cost Indicator	Milieu Kosten Indicator (MKI)
HvT	Hof van Twente (municipality)	-
MEAT	Most Economically Advantageous Tender	EMVI (Economisch Meest Voordelige Inschrijving)
NABO	Unsecured level railroad crossings	Niet Actief Beveiligde Overwegen
SDG	Sustainable Development Goals	Duurzame ontwikkelingsdoelen
SMART	Specific, Measurable, Acceptable, Realistic & Time-related	Specifiek, Meetbaar, Acceptabel, Realistisch & Tijdsgebonden

Glossary

English	Dutch
Ambition web session	Ambitiewebsessie
Contract consultant	Contractschrijver
Cost engineer	Kostenramer
Designer	Ontwerper
Design leader	Ontwerpleider
Program of requirements	Vraagspecificatie
Project controller	Projectbeheerser
Project leader	Projectleider
Project manager	Projectmanager
ProRail	ProRail
Structural engineer	Constructeur
Sustainability consultant	Duurzaamheidsadviseur
Tender dossier	Aanbestedingsdossier

1. Introduction

Climate change, biodiversity loss, pollution and resource scarcity all are societal challenges related to excessive and inefficient use of (virgin) resources (Hanemaaijer, Kishna, Koch, Prins, & Wilting, 2021). A circular economy aids in the reduction of these issues by reducing the use of virgin materials as well as a reduction in energy consumption for the production of these materials. The construction sector can make a major contribution to this as it is a resource-intensive sector responsible for 50% of virgin material consumption (Dutch Ministry of Infrastructure and Water Management, 2016) as well as the production of 33% of the waste in the Netherlands (Hanemaaijer, Kishna, Koch, Prins, & Wilting, 2021).

The concept of circularity in the construction sector is heavily researched in literature. Though in practice, the implementation of circularity in the day-to-day working processes is lacking behind. Most research found aimed to investigate the interaction between different parties in the infrastructure sector. For example, Busse (2018) investigated the barriers and chances for circular innovations in road construction in practice and Gerding, Wamelink & Leclercq (2021) investigated the prerequisites for implementing circular solutions in design projects.

No research has been found in which the focus lay on the interactions and decision-making process between actors within an organisation. This research aims to uncover the working rules that contribute to the development of circular solutions within a project team of an engineering & consultancy firm. It does so through analysing the project process of three design study case projects at the infrastructure department of Antea Group in Deventer. The Institutional Analysis and Development (IAD) framework (Ostrom, 2005) is used to identify the working rules influencing the generation of circular solutions in these case studies through conducting document analysis and interviews with positions in the design teams. It investigates the processual barriers, something Coenen, Volker & Visscher (2022) indicates as the largest impediment in the circular transition of the construction sector.

The results of this study contribute to the level of knowledge related to the implementation of circular principles in practice and provide clear recommendations to bridge the gap between literature and practice. This information can be used to alter processes impeding the generation of circular solutions.

2. Problem statement

2.1. Problem Context

Society is facing many challenges related to its sustainability. Hanemaaijer et al. (2021) attributes substantial challenges such as climate change, biodiversity loss and pollution to an excessive and inefficient use of (virgin) resources. A circular economy could aid in decreasing these issues by providing more attention to material usage. For example, through the reduction in greenhouse gasses related to the production of goods and the reduction of environmental issues due to litter. A circular economy could, furthermore, decrease the resource supply risk and dependence on other states for resources (Hanemaaijer, Kishna, Koch, Prins, & Wilting, 2021). Circularity aids in becoming more sustainable and is a means to achieve a more sustainable economy (Anastasiades, Blom, Buyle, & Audenaert, 2020). This also influences the construction industry as it is, currently, experiencing the start of a major transition. The sector is transitioning from a linear take-make-waste economy towards a circular one. In 2016, the Dutch Ministry of Infrastructure and Water Management published the aim to realise a circular economy before 2050 (Dutch Ministry of Infrastructure and Water Management, 2016). The construction sector is a priority due to its resource-intensive nature. It accounts for 50% of the raw material consumption as well as 40% and 30% respectively of energy and water usage. Moreover, the Dutch construction industry is the biggest generator of waste products in The Netherlands. It produces 33% of all waste in the country (Hanemaaijer, Kishna, Koch, Prins, & Wilting, 2021). The concrete goals put are a 50% reduction in the use of virgin abiotic resources in 2030 and a complete circular economy in 2050 (Transitieteam Circulaire Bouweconomie, 2022). The Dutch Ministry of Infrastructure and Water Management (2016) further specified their goals of a 100% carbon dioxide reduction, high-quality reuse of all materials and a 50% decrease in virgin material use by 2030. These regulations are supposed to urge the construction sector to the creation of circular designs, products and working processes.

In academic literature, the concept of circularity has become substantively researched in the last couple of decades. Delving into the existing body of knowledge shows a multitude of papers researching the concept of circularity, as shown by Munaro, Tavares & Bragança (2020). Kirchherr, Reike & Hekkert (2017) examined 114 definitions of circularity in literature. Other heavily discussed topics are barriers and enablers for the circular economy (Coenen, Volker, & Visscher, 2022; Hart, Adams, Giesekam, Tingley, & Pomponi, 2019; Gorgolewski, 2008; Ruiter, De Feijter, & Wagensveld, 2022). Furthermore, a substantial amount of research on circular construction design strategies already exists. Prominent documents in this field include: circular design principles (Dutch Ministry of Infrastructure and Water Management, 2020), circular design strategies such as Narrow, Slow and Close the loop (Hanemaaijer, Kishna, Koch, Prins, & Wilting, 2021), design for disassembly and design for adaptability (Anastasiades, Blom, Buyle, & Audenaert, 2020) and the need for standardisation (Leendertse, Hendriksen, & Kerkhofs, 2018; Anastasiades, Blom, Buyle, & Audenaert, 2020; Gorgolewski, 2008).

In practice, however, the implementation of circularity in the day-to-day working processes in the construction sector is lacking behind. Hanemaaijer et al. (2021) concluded that the transition towards a circular economy is not progressing fast enough. To ensure compliance with the abovementioned goals of the national government, circularity should be accounted for in every project. This trend is also noticed at Antea Group, a major engineering & consultancy firm in the Netherlands. Antea Group wants to take social responsibility in proactively including circularity in their working process and suggesting circular solutions with and without explicit demand from the client. This not only enhances the focus on sustainable alternatives but also allows Antea Group to anticipate the changing demands. This corresponds with their contribution towards the sustainable development goals (SDGs), especially SDG 9 and 12. In which circular infrastructure and initiative-taking green bids using sustainable methods, alternatives and solutions are highlighted (Frielink, n.d.). Currently, this is not the case.

2.2. Problem description

Too few projects are being completed at the infrastructure department of Antea Group in which circularity plays a substantial role. This does not align with their ambitions as well as the substantial amount of theoretical circular knowledge available. Although there are many circular innovations, tools and strategies available for design teams to use, circularity remains underemphasized in design projects. Even if circularity is a topic debated in design projects, these circular solutions are hardly ever implemented or only in highly diluted form. Something is seemingly hindering the use of circular principles in infrastructure design. this study examines whether the (un)written working rules existing in the current work process hinder the development of circular solutions.

2.3. Research objective

This research project consists of two objectives. The first one is to identify working rules within the design project teams of the infrastructure department of Antea Group and how these rules affect the implementation of circularity in these projects. The second objective is to advice Antea Group on alterations to their design process to generate more circular design solutions.

2.4. Research questions

Similar to the research objectives, two research questions will be answered in this research project. The first research question aims to uncover existing (un)written working rules and their effect on the implementation of circularity. It, therefore, can be described as:

What working rules contribute to the generation of circular solutions in design projects?

Once the existing working rules have been gathered, attention shifts towards analysing how these rules affect the development of circular solutions. The researcher will compare the state-of-art literature on circular design processes with current experiences from design team members at Antea Group to compare the current situation to a more preferred situation. Enabling the researcher to advice on alterations to the current design processes. The second main question can therefore be depicted as:

What can Antea Group alter to their design process to contribute to the generation of circular solutions in design projects?

2.5. Scientifical and societal relevance

The academic focus on the circular transition and especially the construction economy is present for some time now. A lot of emphasis is put on developing novel solutions and creating new frameworks and calculation methods. In the day-to-day working process, however, circular principles are sparsely used. Alongside the development of more innovative technical solutions, more focus should be put on the further transition towards a circular economy in practice. Several studies indicated the gap between theory and practice as a major concern in the circular transition (Coenen, Volker, & Visscher, 2022; Eberhardt, Birkved, & Birgisdottir, 2022; Hart, Adams, Giesekam, Tingley, & Pomponi, 2019; Leendertse, Hendriksen, & Kerkhofs, 2018; Munaro, Tavares, & Bragança, 2020). Even though the tools to develop circular solutions are available, the sector still produces non-circular infrastructure. The long lifespan of infrastructure requires the sector to plan carefully as the design created today will impact daily lives for decades to come. With this research, I intend to aid in the bridging of the gap between theory and practice and contribute my part in the creation of a sustainable future.

3. Background

3.1. Circular construction economy

As stated in the problem context, circularity aids the development of sustainable solutions. Central in the circular transition is the R-model (see Figure 1). This 10-step model provides strategies to enhance the circularity in which R0 is the most circular strategy and R9 the least. The R-model is loosely based on the power of the inner circle as a value creation principle by the Ellen MacArthur Foundation (2013) and Lansink's ladder of waste hierarch (Lansink, 2018). Munaro, Tavares & Bragança (2020) conclude that recycling is the predominant strategy in the infrastructure sector, this view is shared with Arnoldussen et al. (2022) stating that almost 80% of the materials in the Dutch infrastructure sector get recycled.

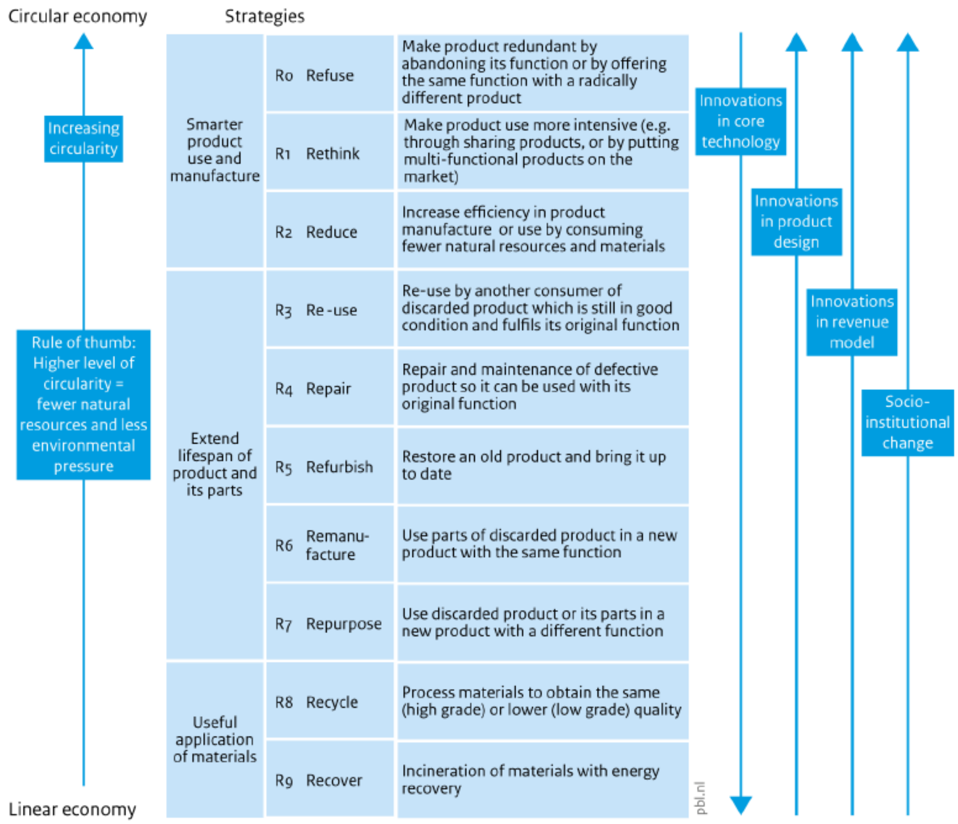

Figure 1 - R-ladder. From (Potting, Hekkert, Worrell, & Hanemaaijer, 2017)

Circularity has been researched substantially in the recent past. This is shown in systematic literature reviews such as Kirchherr, Reike & Hekkert (2017) analysing 114 different definitions of the circular economy, Munaro, Tavares & Bragança (2020), showing 260 publications related to the circular economy in the built environment between 2017 and 2019 and Anastasiades, Blom, Buyle & Audenaert (2020) explaining the differences between sustainability and circularity as they discovered the unclear interpretation of these concepts. Nonetheless, as Coenen, Volker & Visscher (2022) emphasise, little research has been done on circularity as an organisational challenge.

In infrastructure design projects, the concept of circularity remains underemphasised. Many different scholars investigating the circular transition in the construction sector pinpoint the lack of a clear interpretation of what a circular economy is as a major issue. The transition team circular building economy (Transitieteam Circulaire Bouweconomie, 2021), states that a key prerequisite of a circular economy is a clear definition of the concept of circularity. Coenen, Volker & Visscher (2022) conclude that there is ambiguity regarding circularity and alike concepts such as sustainability, CO2-reduction, nitrogen reduction and energy reduction. Anastasiades, Blom, Buyle, & Audenaert (2020) add that the sector suffers from a low industrywide circular awareness. Especially apparent with designers and clients. Munaro, Tavares, & Bragança (2020) describe that the lack of knowledge regarding the concept of circularity hinders its implementation. Multiple different sources state the shortage of circular knowledge as an impediment. They mention the lack of measurability and metrics (Transitieteam Circulaire Bouweconomie, 2021; Munaro, Tavares, & Bragança, 2020). A lack of interest, knowledge and skills (Hart, Adams, Giesekam, Tingley, & Pomponi, 2019) leads to a misassesment of the benefits of a circular solution and, therefore, a focus on less important strategies (Eberhardt, Birkved, & Birgisdottir, 2022) as well as decision-making based on intuition due to the lack of knowledge regarding the circular benefits (Eberhardt, Birkved, & Birgisdottir, 2022). Coenen, Volker & Visscher (2022) connect the lack of available knowledge, shortage of circular knowledgeable staff and a lack of knowledge infrastructure to the lack of learning from pilots and other initiatives to alter organisational processes. In general, the conservative, risk-avoiding and project-oriented culture in the sector hinders the development of novel, circular ideas (Coenen, Volker, & Visscher, 2022) and further complicates gaining the support and willingness to develop circular solutions (Leendertse, Hendriksen, & Kerkhofs, 2018; Munaro, Tavares, & Bragança, 2020). Even though the R-ladder provides some insights into the level of circularity achieved in a project. No quantitative framework to compare and analyse the effects of circular design exist (Leendertse, Hendriksen, & Kerkhofs, 2018; Munaro, Tavares, & Bragança, 2020; Hart, Adams, Giesekam, Tingley, & Pomponi, 2019). This leads to an unstructured decision-making strategy regarding circular solutions with decisions made on intuition (Eberhardt, Birkved, & Birgisdottir, 2022; Munaro, Tavares, & Bragança, 2020).

Based on the literature, a lack of circular knowledge of the positions involved in the design processes becomes apparent. This hampers the decision-making within design projects causing suboptimal circular results. The next section delves into circular design processes by providing an overview of the phases in a design process and what strategies and tools have been researched to include circularity in this process.

3.2. Circular design process

Projects in the Dutch civil engineering sector tend to follow a standardised approach. For example Rijkswaterstaat, the executive agency of the Dutch Ministry of Infrastructure and Water management in the Netherlands, divides its projects into five phases: (1) the initiative, (2) the exploration phase, (3) the development phase, (4) the realisation phase and (5) the management and maintenance phase (Rijkswaterstaat, n.d.). ProRail, the Dutch railway infrastructure manager responsible for the maintenance, renewal, expansion and safety of the Dutch railroad network (ProRail BV, n.d.), define their projects into (1) the preparation, (2) the exploration, (3) the preparatory phase and (4) the realisation phase (Oosterloo, Jansen, & Kuijer, 2022). Phases one to four in both cases are similar and correspond with the phases described in the V-model. The V-model describes how a system is developed through the use of systems engineering (de Graaf, 2019) and can be seen in Figure 2. The V-model divides a project into six phases. The first four compare with Rijkswaterstaat and ProRail. The last two stages are exploitation and demolition.

Important phases for the design process at Antea Group are the preparation and design phases, as the involvement of Antea Group is most substantial in these phases. During the initiative phase, the client initiates a project by describing a problem and if there is enough backing to start tackling the problem. The preparation phase is an exploratory phase in which the client and stakeholder demands are investigated, requirements are specified and several alternative solutions for the problem are investigated. This phase ends with the selection of a preferred alternative. Then the design phase starts.

In this phase, several iterative feedback loops happen to get from an undetailed sketch design to a preliminary design, a final design and eventually a technical design (de Graaf, 2019).

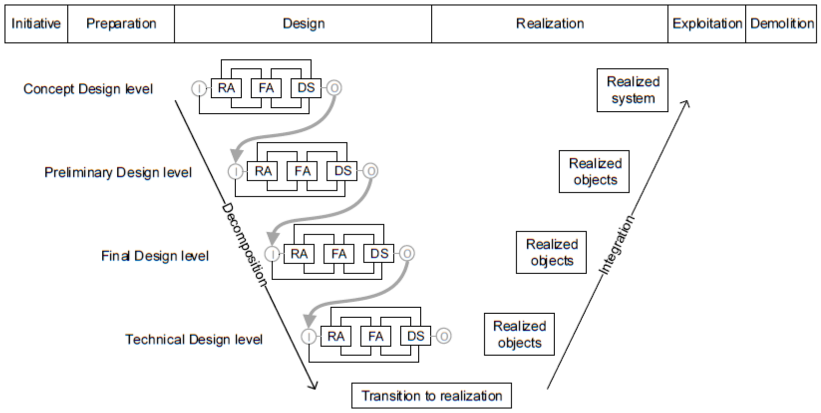

Figure 2 - V-model. From: (de Graaf, 2019)

In 2012, the collaborative partnership sustainable civil engineering sector (Samenwerkingsverband Duurzaam GWW) published a guideline on including sustainability in civil engineering projects. This guideline serves to provide practical tools to include sustainability in civil engineering projects through analysing and seizing opportunities (Samenwerkingsverband Duurzaam GWW, 2012). The key point being made in this guideline is to transform the concept of sustainability into clear and achievable project ambitions. The broad definition of sustainability on the one hand allows projects to mitigate the negative impact on people, the planet and profit. Though on the other hand, makes the concept to wide to develop concrete solutions. The guideline divides sustainability into seven themes. More recent literature, such as the Dutch Ministry of Infrastructure and Water Management (2016) and van Amstel & Winkelmolen (2017), define twelve themes including circularity through the theme Materials. The goal of the abovementioned papers is to establish a new standardised method of incorporating sustainability, and therefore circularity, into civil engineering design processes. These pieces of literature provide clear guidelines on how to implement sustainability into each phase of the design processes as explained above. Figure 3 shows a step-by-step plan to include sustainability in design projects. These steps could be implemented in each phase or when deemed necessary (Samenwerkingsverband Duurzaam GWW, 2012).

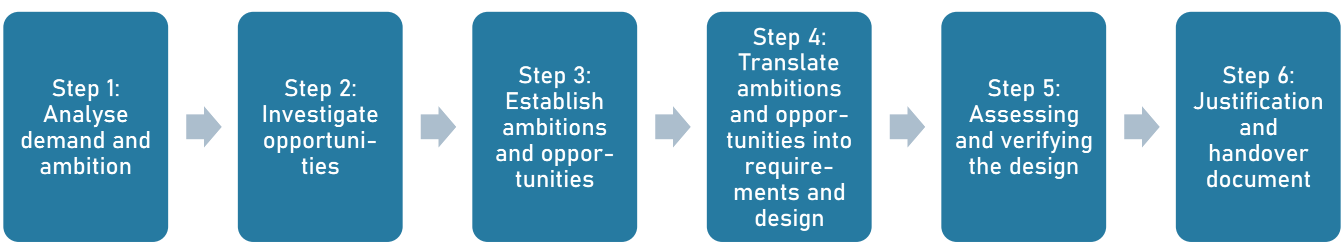

Figure 3 - Step-by-step plan for including sustainability in projects. Adapted from: (Samenwerkingsverband Duurzaam GWW, 2012)

Alongside this step-by-step process, the use of four standardised tools is proposed: (1) the Ambitionweb, (2) the Environment Indicator, (3) DuboCalc ECI calculator and (4) the CO_2 performance ladder. This section will delve deeper into the Ambitionweb and the ECI calculation as these are most often implemented at the infrastructure department of Antea Group. The Ambitionweb is a visual tool to discuss and define the ambitions regarding the twelve sustainability themes. With this tool, the client, stakeholders and consultants can discuss the level of ambition regarding the specific themes in an Ambitionweb session. This can range between ambition level 1: At least as good as the traditional variant. Level 2: A concrete reduction goal that leads to significant improvements on this theme and level 3: Instead of a reduction in negative impact, the goal is to at least have no negative impact or even contribute to a positive impact (Dutch Ministry of Infrastructure and Water Management, 2016). Figure 4 provides an example of an Ambitionweb. The ambition for a circular design can be expressed in the Ambitionweb by scoring the material category high.

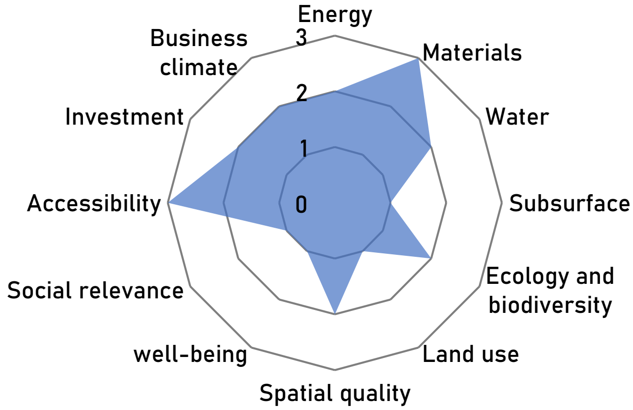

Figure 4 - Example of an Ambitionweb

The DuboCalc ECI calculation tool can be used to calculate and compare the environmental costs of design variants. The costs are presented in euros as the Environmental Cost Indicator (ECI). The system is based on the LCA method and utilizes quantities of materials and a table of shadow costs that are used to monetise environmental impacts (Samenwerkingsverband Duurzaam GWW, 2012; Dutch Ministry of Infrastructure and Water Management, 2016). Van Amstel & Winkelmolen (2017) state that projects in the civil engineering domain mainly use a traditional design approach focussed mostly on optimizing the costs of the realisation phase. This traditional approach limits the possibility to seize sustainable opportunities. They furthermore pinpoint a lack of focus and awareness on the topic which causes sustainability to be seen as complex and constricting. This is non-surprising given that the traditional approach has become routine based on years of experience and little tweaks. Becker (2005) explains that breaking that routine by introducing new criteria such as circularity or sustainability decreases the smoothness of operation as you can no longer just rely on the developed routines and intuition. Eberhardt, Birkved & Birgisdottir (2022) and Munaro, Tavares & Bragança (2020) show that many decisions in the construction industry are made on intuition. This further complicates the inclusion of the new criteria.

Examining the literature on the role of a design team, it is remarked that much is written regarding tools and strategies available to the design team. These include for example the circular design strategies (Dutch Ministry of Infrastructure and Water Management, 2020) and the standardisation of components to make reuse easier (Anastasiades, Blom, Buyle, & Audenaert, 2020; Gorgolewski, 2008; Leendertse, Hendriksen, & Kerkhofs, 2018). Also, research has been conducted on how circularity within design teams can be enhanced. This can be done by including sustainability experts (Crielaard, Chahboun, & Bakker, 2019; Gerding, Wamelink, & Leclercq, 2021), the need for designers to be flexible (Gorgolewski, 2008) and a change of mentality in which designers are limited by the available components instead of having a limitless set of components (Munaro, Tavares, & Bragança, 2020).

Gerding, Wamelink & Leclercq (2021), have been looking into circular decision-making rounds for building projects in the pre-phase (initiation, preparation and design phase). They identified, based on three case study projects, that actors within the project team have a substantial influence on the decision-making process but that they mainly lacked the required circular knowledge to make informed decisions. Actors with substantial influence were clients, project managers, designers and main contractors. Actors with circular knowledge (experts and dismantlers) could however influence decision-making by providing the requested circular knowledge the project team members lacked. They, furthermore, concluded that actors positioned centrally in the network can accelerate the circular implementation. Although Gerding, Wamelink & Leclercq (2021) considered the decision-making moments as rounds according to the rounds model (Teisman, 2000). They explored what decisions have been made at which moment in time but did not focus on how these decisions were made. They did not analyse the mechanisms acting within the decision-making rounds. These mechanisms that influence decision-making, however, are worth delving into in this research as they may uncover impediments towards implementing circular solutions.

Much of the abovementioned research investigated the interaction between different companies and partnerships. No research has been found during the literature review in which the focus was not on the interaction between different parties but on the interaction within a party. No research in which the working rules of a design team and the reasoning for making certain choices has been discovered. This research project thus contributes to filling that gap while also addressing the problem Antea Group is facing.

3.3. Institutional Analysis and Development Framework

Analysing the working rules that dictate the way people interact and make decisions is a complex issue. Therefore, it can be useful to adopt an existing framework to structure the analysis. Several potential frameworks have been researched. The Institutional Analysis and Development (IAD) framework was deemed most suited as it can be used to both identify working rules as well as analyse how these identified rules contribute to the development of circular solutions. It, therefore, is preferred over the Rounds model by Teisman (2000) as this one can be used to analyse the interaction between actors in a design team, though does not allow the identification of specific categorisations of rules and how they contribute to the development of circular solutions. Activity theory, as described by Engeström (2000) was deemed inadequate to answer the research questions. Activity theory focusses on the effects of a change in activities based on a framework of interactions between multiple elements. A changing activity often alters elements such as the tools used, the subject that uses the tools, the division of labour and the purpose of the activity. In this case, no clear change in on of these elements can be noticed. This theory, furthermore, has a predominant focus on tasks and not on the reasons (working rules) for conducting those specific tasks.

3.3.1. Introduction

The Institutional Analysis and Development framework (Ostrom, 2005), can be used in this context to provide a deeper understanding of the (unwritten) rules that dictate decision-making in design teams. Ostrom (2011) describes that the IAD framework can be used to analyse institutional arrangements, the rules that structure social interaction (Hodgson, 2006). An institution can consist of written and unwritten rules that govern the way people treat each other in a specific repetitive and structured situation. Those situations can be formal such as participating in a football match where certain participants have distinct positions and corresponding actions. A referee is allowed to do different things than goalkeepers, midfielders, or coaches. But also, in situations with less formally written rules such as how to interact with your neighbours, and how to behave in a supermarket.

Rules serve as instructions on what you may, must or must not do in a certain situation. They can be different from situation to situation depending on the context. These rules share similarities with what Becker (2005) refers to as routines. The development of institutional rules can also develop based on previous experiences and learnings from those experiences. Most rules, therefore, are basically working habits that people are unaware of. Rules do not need to be written down to exist. Like routines, individuals create institutional rules to change the structure of repetitive situations to enhance the outcomes. This can be done both consciously and subconsciously (Ostrom, 2005). The IAD framework can be used by the researcher to find out what rules exist, why these exist and how these rules shape the process and outcomes. This rigorous analysis enables the researcher to provide substantiated recommendations on how to tackle the research problem (Ostrom, 2005).

3.3.2. Action situations

The abovementioned examples of a football match or a meeting with your neighbours can be regarded as action situations. Action situations exist if multiple actors must interact to jointly produce an outcome from several potential actions that can be chosen. The IAD framework (Ostrom, 2005) describes an action situation with seven variables: (1) Actors, (2) Positions, (3) Actions, (4) Information, (5) Control, (6) Costs and Benefits, and (7) Potential outcomes. The structure of an action situation is displayed in Figure 5.

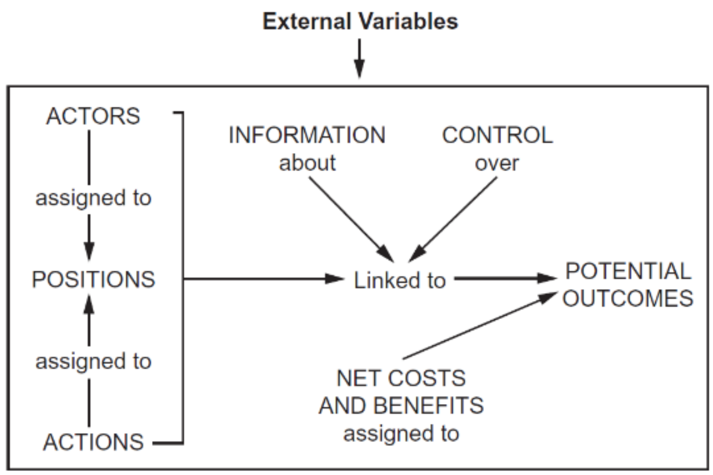

Figure 5 – Structure of an action situation. From (Ostrom, 2011, p. 10)

In this research project, the design process of a civil construction can be regarded as one action situation. The variables within the full design process remain relatively equal. The actors involved in the design team as well as their positions are set at the start of the design process. Information is constantly updated throughout the process and decisions making is an ongoing process characterised by frequent informal interaction between the actors. Therefore, there are no hard boundaries within the design process that allow a new action situation to emerge. The seven variables are explained in Table 1 and are based on Ostrom (2005).

Table 1 - Variables in an action situation

Variable	Explanation
Actors	Actors are entities to which a position is assigned. Each actor can select which action he wants to pursue. Relevant attributes in describing the action situation related to actors are the number of participants, whether they are individuals or represent a team, group or organisation and individual attributes of the actor (such as age and education level).
Positions	Positions often determine the actions that a certain actor can perform. Mostly, there are fewer positions than participants, meaning that multiple participants can claim one position.
Actions	Actions are individual moves that actors can take to affect the outcomes. The set of actions that an actor takes to get to an outcome is called a strategy.
Information	The information provides the basis on which actors create their strategies. Information in empirical situations is often incomplete. In action situations, there often is asymmetric information. Actors are specialists and deliver specific information to the table. More information can lead to better decisions as it often clarifies how actions are linked to potential outcomes.
Control	Actors hold distinct levels of control over a situation. Control is the chance of affecting an outcome to your desired outcome. Control gives power, but only if there is an opportunity to apply the control.
Costs and Benefits	The actions that need to be taken to get to an outcome generally are considered the costs. The outcome achieved can then be seen as the benefits. Costs and benefits can be monetised, but strongly depend on the intrinsic valuation. The perceived benefits can be higher if an actor feels proud of his achievement and can be lower if there are regrets about choices made.
Potential outcomes	This variable lists the solution space from which outcomes are generated. These outcomes have certain costs and benefits assigned to them. Important is to remember that outcomes have different values to them based on the perception of actors on the outcome. For example, actors that have a strong intrinsic motivation to develop circular solutions value circular solutions higher than actors that are indifferent to circularity.

3.3.3. Rules

Rules, for example, the rules of football or traffic rules, are crucial in the analysis of institutions. Ostrom (2005, p. 18) describes rules as: *"Shared understandings by participants about enforced prescriptions concerning what actions or outcomes are required, prohibited, or permitted."* There are many ways of developing rules, but they are created to improve outcomes by evaluating previous experiences and adjusting behaviour accordingly. This makes these rules strongly related to the development of routines discussed by Becker (2005). The rules shape the action situation by determining what may, must and must not be done in an action situation. Rules can be classified based on which variable of the action arena they shape. Classifying rules aids the researcher in understanding how action situations are constructed. The rules can be classified into seven categories. These categories are based on which variable in the action situation the rule influences. Which rules influence which variables can be seen in Figure 6.

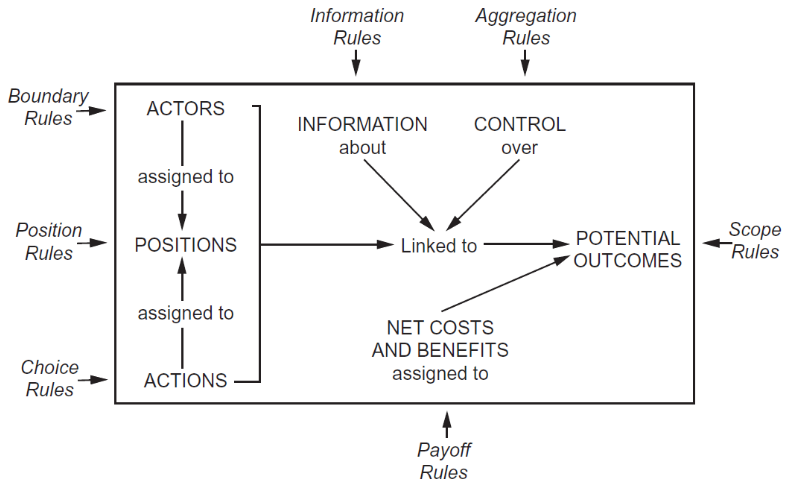

Figure 6 – Working rules. From (Ostrom, 2011, p. 20)

The seven categories are explained in Table 2. The descriptions show the researcher's interpretation of the rules as explained by Ostrom (2005; 2011). In addition to that, the researcher used recent applications of the IAD framework in research that is more in line with the topic of this research paper. The works used for this are Busse (2018), Duenk (2019) and Neef, Busscher, Verweij & Arts (2022) which are explained in Section 3.3.4 below.

Table 2 - Explanation of categorisation of rules

Category	Explanation
Boundary	Boundary rules define who can enter or exit the action situation. They define who is allowed to enter a position. How a process determines who may or must enter a position (Ostrom, 2005) Examples of these are specific criteria an actor needs to meet to enter a position (advisors need X years of experience to become a senior advisor). This description of boundary rules is in line with the descriptions of Busse (2018), Duenk (2019) and Neef, Busscher, Verweij & Arts (2022).
Position	Position rules determine who can be in which position. They link actors to specific sets of actions and levels of authority. Position rules can, furthermore, be used to determine the number of actors that can hold a certain position (Ostrom, 2005). There can for example, only be one design team leader, but multiple designers can join. This description is in line with Duenk (2019) and Neef, Busscher, Verweij & Arts (2022). Busse (2018) adds that it also includes the objectives and ambitions of the different positions and whether they align.
Choice	The actions that a specific actor in a position may, must and must not do are determined by the choice rules. However, if actions directly impact the available information, positions, control or net costs and benefits, these actions should be placed in the corresponding category of rules. Choice rules can also distribute control over the positions (Ostrom, 2005). For example, if the action of agenda setting is limited to one position, that position holds power over what will be discussed in meetings. This is in line with Duenk (2019) and Neef, Busscher, Verweij & Arts (2022). Busse (2018) adds that both the objective choices available as well as the perception of these choices. A certain choice might objectively be an option, though, if the actor making that choice is unaware of the possibility, he will never choose it.
Information	Information can affect decision-making. Not only information regarding the solution space and which alternative seems to be best suited to the criteria but also information regarding the preferences of other actors. Competitive advantages can be gained by keeping certain information to yourself. In a team environment information is shared with all members of the team. However, the team is created based on the expertise of the individual members. Therefore, some information can be regarded as more important to some actors (Ostrom, 2005). Busse (2018) adds that it also includes the way that information is shared between actors.
Aggregation	Aggregation rules define how decisions are made. Is this a democratic decision? Is decision-making limited to certain positions? Aggregation rules also determine what happens if no agreement can be made. Will the decision-making be postponed? Will one position be able to decide, or will a random decision be chosen? Common examples of aggregation rules are majority vote, unanimous agreement, and one-man decision (Ostrom, 2005). This description of aggregation rules is in line with the descriptions of Busse (2018), Duenk (2019) and Neef, Busscher, Verweij & Arts (2022).
Payoff	Payoff rules determine the costs and benefits of the project for different parties. The method by which benefits are gained can vary, just like the perception of how high certain benefits are. An important characteristic of payoff rules is the frequency of interaction. What might seem like the best solution in the short term (often individualistic opportunistic behaviour) may be detrimental in the long run. if an actor feels like he has been taken advantage of by another actor, he will be less inclined to collaborate with that actor again (Ostrom, 2005; 2011). Neef, Busscher, Verweij & Arts (2022) contribute that the payoff rules tend to affect the availability of resources. Project management theory dictates that within a project, there must always be a consideration between cost, time and quality (Fewings & Henjewele, 2019).
Scope	Scope rules determine the solution space. They specify the criteria that chosen solution should meet. In design projects, the project brief prescribes the criteria. Though, these project-specific criteria can change when new information becomes available or other factors influence the scope of the project (Ostrom, 2005). Duenk (2019) adds that scope rules link actions to specific outcomes.

3.3.4. Application of the framework

The rules that shape the action situation can be determined by analysing specific cases. The IAD is particularly useful for gathering multiple existing working rules and placing them in distinctive rule types. The IAD framework does so by analysing perspectives that are qualitatively rich and cannot easily be quantifiable with other methods. The insight into these working rules explains how institutions shape specific collective action (Neef, Busscher, Verweij, & Arts, 2022). Uncovering the (un)written rules enables the researcher to gain an overview of how decisions are being made.

The IAD framework has been extensively used in academic research. In Ostrom (2005, p. 9), already over twenty studies between 1989 and 2005 regarding multiple different empirical settings are mentioned. These include, for example, research on common-pool resource settings, but also on institution decision-making processes in governmental organisations, developments of cooperation and comparison of non-profit, profit and governmentally led organisations (Ostrom, 2005). Van Heffen & Klok (2000), use it to describe and distinguish different state models by analysing the mechanisms that influence the interaction within a system defined by boundaries. They use diverse types of rules to distinguish between markets, hierarchies and network state-models. More recently and closer to the topic of this research project, Busse (2018) utilizes the IAD framework for analysing decision-making processes from Rijkswaterstaat in a highway broadening project in The Netherlands where circular innovation is key. The IAD framework provided insights into the institutional barriers and enablers experienced in this project. With the use of documentation analysis and semi-structured interviews, Duenk (2019) used the IAD framework to identify working rules in the implementation of smart mobility in a pilot program in the south of the Netherlands. It used the gathered rules to recommend improvements towards the implementation of smart mobility in the Netherlands. Lastly, Neef, Busscher, Verweij & Arts (2022) published an article in which they used the IAD framework to analyse the collective decision-making in two bridge maintenance projects in The Netherlands. They introduced rule directions combined with analysing the working rules to explain the outcomes of collective decision-making.

Implementing circular solutions can be regarded as an innovation in the design process. This innovation, however, requires a new way or altered method of working. This challenges established rules. This framework enables the researcher to understand the existing rules and enables him to pinpoint potential impediments to be dealt with or improvements that are required to work towards implementing more circular solutions. The method of gathering the required data and the way this data will be analysed can be found in Section 4.

4. Research methodology

The researcher intended on solving a real-life problem through a scientific approach. There is little control over the problem to be investigated and quantitative data is difficult to gather. Case study research is well suited to this as case study research can develop: *"Rich, empirical descriptions of particular instances of a phenomenon."* (Eisenhardt & Graebner, 2007, p. 25). Furthermore, it matches the types of data that are available for researching as mainly project-specific documents and knowledge is available. Yin (2003, p. 8) emphasizes the unique strength of case study research, in relation to other types of research, to be: *"the ability to deal with a full variety of evidence: Documents, artifacts, interviews and observations"*.

The goal of this research project is to identify working rules within design teams at the infrastructure department of Antea Group and how these rules affect the implementation of circularity in these projects. Additionally, to provide Antea Group with recommendations on alterations to their design process to enhance the incorporation of circularity. The proposition that there are working rules that influence the generation of circular solutions in the design processes of civil structures, will be investigated. As well as that the moment in which circularity is introduced as a criterion influences the working rules and therefore the generation of circular solutions. The unit of analysis can be defined as the design processes of the infrastructure department of Antea Group.

4.1. Cases

Case studies are characterised by multiple factors, a major factor is whether it is a single case study or a multiple case study. Yin (2003) States that multiple-case studies are often stronger than single-case studies. Data from multiple-case studies is more compelling and makes the study more robust (Yin, 2003). It also creates a stronger base for theory building as two cases, although seemingly similar, have different contexts. Similarities that arise despite these variables expand the generalisability of the research. (Eisenhardt & Graebner, 2007; Yin, 2003). Cases, in the multiple-case studies are individual experiments that allow for replication. Replication is desirable because it can be done to determine whether multiple cases produce expected results in accordance with the proposition. Yin (2003) describes that replication can be done by either conducting similar experiments expecting comparable results or experiments with contrasting variables yielding contrasting results. This research aims to identify the working rules of design teams through the analysis of multiple projects that share many variables except for the way circularity was included in the projects. This is chosen to analyse how the identified working rules yielded such different implementations of circularity even though most variables are shared. This information will be used to recommend changes to the process to enhance the inclusion of circularity. Cross-case analysis has been used to compare the cases. The researcher, therefore, inquired specifically for cases in which many variables were similar except for the inclusion of circularity in the projects.

Apart from the main criterion for choosing cases that have a lot of common variables apart from the inclusion of circularity, several other requirements for selecting cases have been set.

- As the research is interested in the working rules that exist in projects in which the design team of Antea Group is responsible for the design, only projects in which employees of Antea Group designed a fixed civil structure were considered. This prevented the inclusion of cases in which part of the design was outsourced or the responsibility of another organisation.
- Case projects should involve the creation of a new structure or the replacement of an existing structure. Only conducting maintenance on a structure is not sufficient as the tasks needed to complete, and the number of raw materials needed for this are too few to actually start taking circularity into account.

- To ensure the findings are representative of the design processes at Antea Group, circularity must play a role in the project. Though, it should not be a special pilot project in which design processes differ too much from regular design processes. The uniqueness of these projects hampers the possibility to generalize the findings and apply these findings to other more traditional projects.
- For triangulation purposes, both the actors involved in the design team of the projects as well as project documentation should be accessible to the researcher.
- To be able to analyse the complete process of a project, the handover of the project should have been finished at the moment of conducting the case study.

Three case projects have been found that match these requirements. All these projects were projects in which a railroad crossing was being replaced with a railroad underpass. Two of these projects are part of a framework contract between ProRail and Antea Group. These projects are part of the NABO framework contract in which 180 publicly accessible unsecured level crossings (NABO) will be eliminated and replaced with (1) a secured level crossing, (2) a tunnel underneath the railroad, (3) a bridge crossing the railroad, (4) the rerouting of the road towards another railroad crossing or (5) simply the elimination of the crossing (see Figure 7 and Figure 8 for an example). Antea Group was granted the contract to perform the conditioning studies and the preliminary design of the new situation for all projects in which the preferred alternative is of category two, three or four. The two identified projects are the NABO at Almen and the NABOs in the municipality of Hof van Twente (HvT).

The NABO at Almen was one of the first projects in the framework agreement that was conducted. It involved the replacement of the level crossing at the Hulzedijk with a tunnel. The Hulzedijk is primarily used for pedestrians, cyclists and horseback riders near Almen in the municipality of Lochem. Circularity is only included in the last step of the design phase using an ECI calculation. The project ran between 2019 and 2020. The actual construction of the underpass was finished in 2022 (ProRail BV, 2022). Figure 7 and Figure 8 show the old and new situation of the crossing.

Figure 7 - NABO Almen old situation

Figure 8 - NABO Almen new situation

For the second case project, Antea Group designed three new underpasses for the municipality Hof van Twente. These are the NABO Keizersteeg in Ambt Delden, NABO Herikervlierweg in Markelo and the NABO Heijinksweg in Goor. These three underpasses were different projects for Antea Group, though, are considered as one case in this research as these projects ran at similar moments in time (2020 till 2022), and the project team members were equal for all three projects. Circularity was included in the project through a sustainability session halfway through the design process.

The last case of the multiple case study is the case of the railroad underpass in the N631 near Rijen. This used to be a level crossing between the railroad and the provincial road but to increase safety and traffic flow, an underpass was deemed necessary. Antea Group was already involved in the planning study on safety and flowthrough along the whole N631. One of the conclusions from the planning study was to create an underpass. Antea Group was re-commissioned to design the underpass as well.

Circularity was considered in this project from the very beginning. Figure 9 illustrates the current situation and Figure 10 shows an impression of the new situation. An overview of the cases and specific details can be seen in Table 3.

Figure 9 - Railroad crossing N631 current situation (ProRail BV, n.d.)

Figure 10 - Railroad underpass N631 impression new situation (ProRail BV, n.d.)

Table 3 - Case studies

Variable	Almen	HvT	N631
Type	Railroad crossing replaced with a railroad underpass	Railroad crossing replaced with a railroad underpass	Railroad crossing replaced with a railroad underpass
Time	2019-2020	2020-2022	2019-2020
Scope	Conditioning studies, systems engineering, preliminary design and handover phase	Conditioning studies, systems engineering, preliminary design and handover phase	Conditioning studies, systems engineering, preliminary design and handover phase
Client	Municipality of Lochem and ProRail	Municipality Hof van Twente and ProRail	Province of Noord-Brabant and ProRail
Circularity included	After the design	Halfway through the design	At the start of the project
Circularity requested by	Client	Client	Client

4.2. Data gathering

As set in the case requirements, both the actors that were involved in the design of the underpass, as well as corresponding documentation, should be available for the cases. This allows for triangulation of the data which, increases the internal validity of the research project and therefore the research quality. More concrete steps taken to increase the research quality are explained in Section 4.4. This section elaborates on the techniques used to gather the required data. Three main methods of gathering data have been used. The first step was conducting a desk study on the available documentation regarding the cases. The researcher had access to the Microsoft Teams project environments of all three cases. Reports such as Customer Requirements Specifications (CRS), System Requirement Specifications (SRS), designs, design justifications, sustainability memos, validation and verification reports, schedules and the internal message system have been investigated. Subsequently, the data gathering shifted from desk study to field study research by conducting interviews. Interviews are seen as highly efficient in gathering rich, empirical data (Eisenhardt & Graebner, 2007) and a vital source of case study information (Yin, 2003). Nonetheless, a major concern in dealing with interview data is that it can be biased, or poor recall of the interviewees (Eisenhardt & Graebner, 2007; Yin, 2003). Several measures have been taken to reduce this risk. Using multiple and knowledgeable informants with different perspectives as well as comparing interview data with the data gathered in the desk study for triangulation purposes. Furthermore, all interviews have been conducted using a similar interview scheme. This increased the comparability. However, to be able to gather rich empirical data, a semi-structured approach has been selected. The interview scheme can be found in Appendix A.

Ten semi-structured interviews were conducted with Antea Group employees that had a role in the design team. Interviews were held with actors in positions that are directly involved in the design process (designers, structural engineers, cost engineers & design leaders) and positions that influence the design process (project managers, project leaders, project controllers, contract consultants). Lastly, the sustainability consultants (in which circularity is included) from all three case projects were interviewed as well. These positions were chosen based on the information gathered in the desk study. As the case projects are similar, some employees participated in multiple case projects. This can be seen as a strength as these actors could provide insight into the differences between the cases for the cross-case analysis based on their experiences with the cases. But also, as a weakness as the investigated sample is smaller, decreasing the external validity. Besides, one actor held sometimes multiple positions. Lastly, not all positions for all the case projects could be interviewed as not all actors are still employed at Antea Group. Nonetheless, ten semi-structured interviews have been conducted between 27-02-2023 and 16-03-2023. These interviews were held either in person on-site at the office of Antea Group in Deventer or online through MS teams. The interviews have been recorded for transcribing purposes. An overview of the interviews, the positions each interviewee had in each project, and the date and location of the interviews can be found in Appendix B.

4.3. Data analysis

Data analysis should, preferably be conducted using an analytic strategy (Yin, 2003). Data analysis serves to shift the unstructured bulk of data gathered into structured, usable and combined information that can be used to check the propositions made and answer the research questions. The analytic strategy conducted in this research is a cross-case analysis focusing on the similarities and differences between the working rules based on the categorisation of the IAD framework in design teams that contribute to the development of circular designs. A cross-case analysis is selected as it aggregates the findings across a series of individual experiments. To make the data insightful, several analytic manipulations have been performed. Yin (2003) describes the creation of word tables that display the data from individual cases according to some uniform framework as a suitable strategy for analysing the data. Therefore, the data is presented by showing tables listing the specific working rules identified through the research per IAD category as described in Table 2. Alongside that, chains of events for each case have been developed to visualise the differences between the cases. These results can be found in Section 5., this section continues by explaining the steps taken in the analysis of the data.

The data analysis started by transcribing the interviews. The ten interviews conducted yielded around 9 hours of recorded conversation in the MP3 format. This has been transcribed using the transcription software available in Microsoft 365 Word Online. After uploading the MP3 recording, the software attempts to transcribe the recording. After this, the researcher listened, checked and rewrote every sentence using the software. After completing a full interview, the researcher reread the interview and anonymised it by replacing names with function titles.

After all the interviews were transcribed. The researcher read the interviews and coded any statement related to the following criteria:

- based on whether he could link it to a certain category of rules.
- or whether it describes a chance or impediment
- What the interviewees describe as issues or difficulties or important.
- Information that can indicate cause-effect relationships.
- Points that are mentioned more often or contrast with other interviewees.

The findings were summarised per interview and validated with the interviewees to ensure the researcher correctly understood the interviewee and interpreted the interviewees' answers correctly to minimize interpretation bias. The feedback on the summaries was limited to small comments, some spelling mistakes, renaming and some small additions and clarifications. This feedback has been incorporated into the proceeding steps. The researcher then tried to reconstruct the cases by describing for each case what happened, in which order and why certain activities related to circularity did or did not happen. As well as describing who was incorporated at which point of the process. This explanation is provided in Section 5.1. The researcher then conceptualizes the data by collecting all insights that he interpreted to match a certain category of rules and the interaction and cause-effect relationships between the distinct categories of rules. An example is provided in Figure 11.

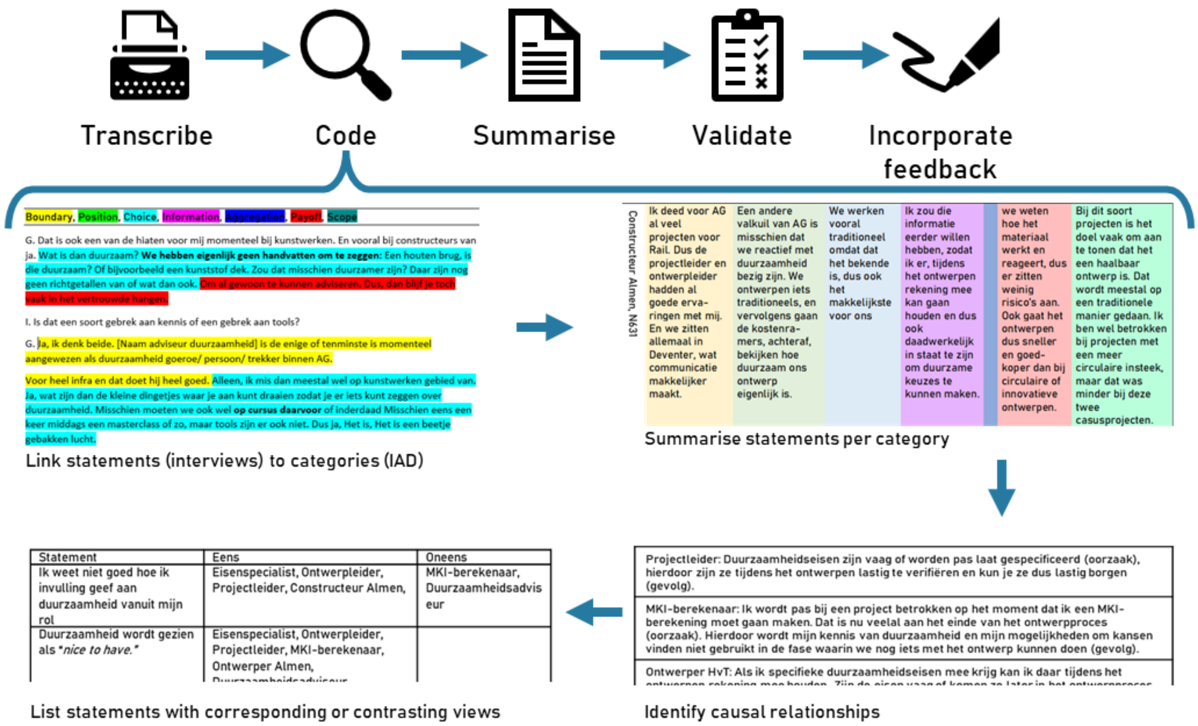

Figure 11 - Example of interview data analysis

Following this, a first set of working rules based on the organised statements has been developed and then specific quotes from the interviews were connected to increase credibility. As the interviews have been held in Dutch, the quotes have been translated into English. This set of rules is presented in Section 5.2. These results have been discussed with an expert that has conducted research with the IAD framework before to minimize interpretation bias.

The consecutive part of the analysis focuses on how the rules influenced the generation of circular solutions. The design process was visualised including the distinct phases, core activities of the phases and positions involved in each phase. Consequently, the interaction between the rules and the process was visualised to provide insight into how these rules interact with each other and influenced the generation of circular solutions in the cases. Following this, a cross-case analysis was conducted comparing the three different cases of working rules identified and their effect on the generation of circular solutions.

4.4. Research quality

The quality of case studies can be judged with four tests. These are construct validity, internal validity, external validity and reliability (Yin, 2003). Construct validity deals with the question of whether the thing that is investigated actually is the thing that was intended to be investigated. In this research, the construct validity is improved by incorporating expert feedback on the draft results. Internal validity deals with whether the conclusions made match and defines the gathered data. Several steps have been taken to enhance the internal validity. To check whether the interviewer interpreted the interviewees correctly, a summary of the interview has been sent to each interview to verify this. Furthermore, the cross-case analysis using replicated experiments and triangulation increased the internal validity as the drawn conclusions match the data of all cases. Lastly, an expert that has done similar research with the IAD framework reviewed both the description of the categories provided in Table 2 as well as the working rules determined based on the data in Section 5. The external validity can be regarded as limited. The design of the multiple-case study placed a preference on selecting similar cases, this might limit the generalisability of the results. The discussion will present ideas for future research improving the external validity of the research. Research is reliable if repetition of the research will yield similar results. Replicating case studies proves to be challenging. The researcher, nonetheless, put a lot of effort into describing the procedure clearly and traceably. With the help of appendices A and B, other researchers could trace the relevant interviewees and ask them the same questions again to check if the data matched. The same applies to the analysis of the data, by clearly describing how the researcher placed rules in specific categories and what assumptions were taken, they are reproducible.

5. Results

To uncover the working rules and highlight the differences that have been found between the cases, first a description of the process of all cases has been made. Subsequently, tables are provided for each uncovered working rule including an explanation and for which case that rule applies.

5.1. Findings: Design process

The first step is to understand how the project teams were built up to uncover the position rules and boundary rules. A difference between the NABO projects and N631 exists because the N631 is a multidisciplinary project. A brief description of the positions interviewed and corresponding actions is provided in Table 4. The organisational charts for the projects can be viewed in Appendix C.

Table 4 - Positions and corresponding actions

Position	Description
Project manager	Primarily responsible for contract management and gets involved in case of conflict between the project leader and client as a form of escalation. The project manager is not that much involved with the design itself.
Project leader	The primary point of contact with the client. The project leader creates the bid, selects the project team members and manages the project team. Further responsibilities are scope management, progress reports, meetings, and invoicing.
Technical manager	Similar actions to the project leader though not only responsible for the rail design team but all design teams involved.
Project controller	Tasked with controlling the progress of the project. Responsible for document management, scheduling, risk management and the verification of products and services.
Design leader	Managing the design team. Responsible for steering the design team to meet the scope and requirements for the project. Contact with the client on design-specific aspects. Technical verification of design products and services.
Designer	Tasked with the identification, combining and mapping of the current situation and results of the conditioning studies. Then tasked with the spatial integration of the construction in the existing environment and the eventual design of the product and site planning.
Structural engineer	Tasked with executing the structural calculations of the construction and consulted on the method of construction, site planning and in the case of rail projects the train-free periods required to execute the work.
Cost engineer	Tasked with estimating the costs of building the project.
Sustainability consultant	Regarded as the expert on sustainability (including circularity) in the project team. Tasks vary based on the client's request. Either plans and conducts sustainability sessions to generate and specify sustainable ideas and ambitions or calculates the environmental costs of a design expressed in the Environmental Cost Indicator.
Contract consultant	Specifies customer requirements and develops the system requirements based on customer requirements and guidelines. Develops the program of requirements (for the execution of the work) and the tender dossiers for the client.

A process chart for each case is developed based on the available documentation and interviews. This chart shows the distinct phases in the projects, the core activities in these phases related to circularity, key documents or activities held in each phase and which positions are involved in which phase of the project. The Almen case is presented in Figure 12 as an illustration. All three process charts can be found in Figures 18, 19 and 20 in Appendix D.

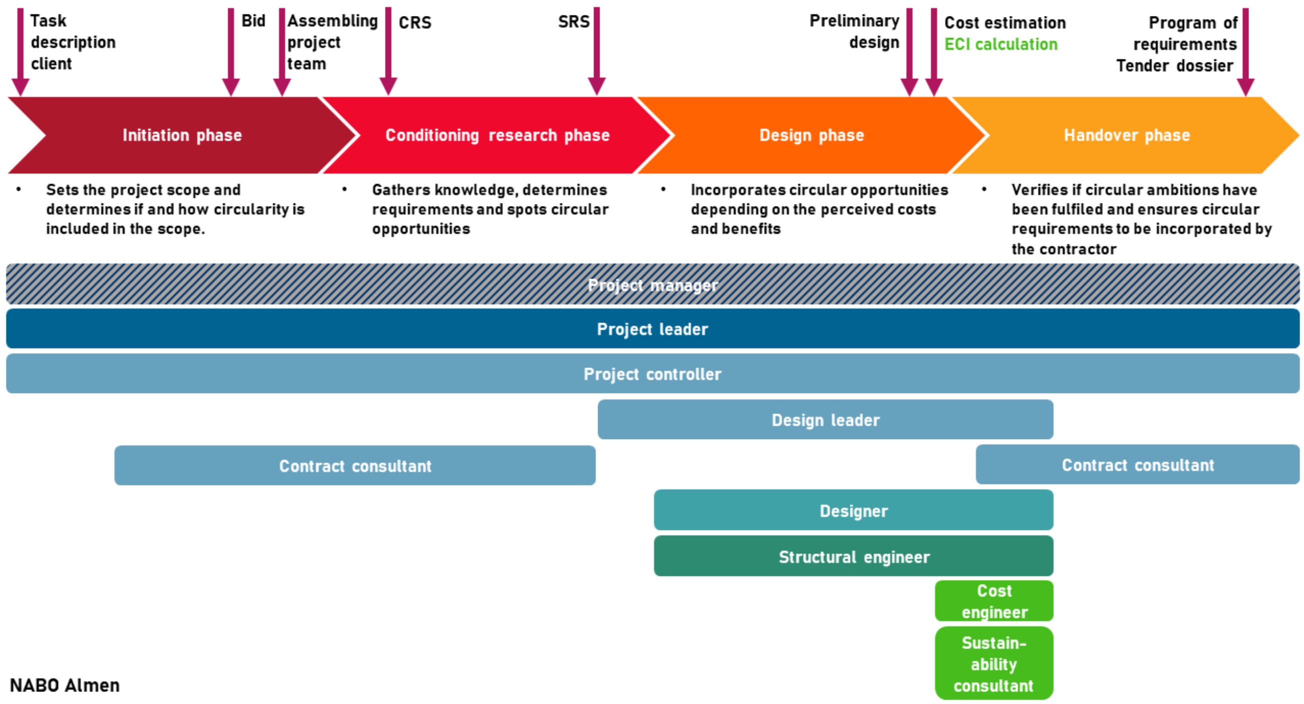

Figure 12 - Timeline NABO Almen

The goal of these projects is to investigate the preparatory processes and make a preliminary design based on the conditioning studies and customer requirements to see if such a design is feasible. If the client intends to continue with the project, the creation of the final design will be retendered on the market. Antea Group's tasks in these types of projects can be divided into four phases. In the initiation phase, the project leader receives a list of tasks from the client. These are the tasks the client would like to see fulfilled by Antea Group. The project leader analyses the list and prepares a bid based on the tasks. This bid includes which positions will be working for how many hours on the project to fulfil the tasks. In this phase, the core activity is to set the scope of the project including the schedule, budget and what positions to include to achieve the tasks. This phase, therefore, defines whether there will be lead time and budget reserved for implementing circularity in the project.

The second phase in these projects is called the conditioning research phase and starts once the client accepts the bid. The project leader then assembles the project team by assigning actors to the positions. During the conditioning research phase, all required investigations before design are conducted. Besides that, systems engineering takes place to specify the clients' wishes into requirements. These customer requirements are combined with the requirements from guidelines and the conditioning research to form the systems requirement specification (SRS). Core activities related to circularity in this phase are gathering knowledge, determining project requirements and spotting circular opportunities to incorporate in the design phase.

The design phase is the third phase of these projects. In the design phase, the designer and structural engineer develop one or multiple variants that meet the requirements and the design leader will check these. The cost engineer then estimates the costs of the design. The output is checked once more by the project leader before handover. Circularity can be incorporated in this phase by designing the circular opportunities spotted in the previous phase and new opportunities discovered during the design phase as well.

Once the preliminary design is finished, the last phase of the project starts. In this phase, the program of requirements and the tender dossier are created. The program of requirements states all requirements that the contractor, who will be responsible for the development of the technical design and the realisation of the project, should meet. The tender dossier is a composition of all products going to the market. Antea Group composes the tender dossier for ProRail so that ProRail can distribute it to all contractors that intend to create a bid.

After the handover of the program of requirements and tender dossier, the role of Antea Group shifts from active to reactive. In the tendering phase, Antea Group is still on standby to deal with questions from contractors to ProRail. so which position to call on will then depend on the content of the questions received by ProRail. This phase is excluded from the scope of this study as Antea Group is on standby but no longer actively involved in the project itself.

5.2. Findings: working rules

Boundary rules

Three boundary rules have been identified. These rules relate to how an actor can join a project team and when that actor enters and exits. They are displayed in Table 5.

A project at Antea Group starts with a client request. This starts the initiation phase in which the project leader analyses the request and develops a bid based on the specified products the client wants to be produced. In this bid, the project leader defines which positions are required to fulfil the demands of the clients and approximately how many hours an actor will spend on a product. There are experts for every position within Antea Group and these actors primarily fulfil their corresponding positions. If the client accepts the bid, the project leader assembles a project team by assigning specific actors to the roles defined in the bid. The selection of actors is based on (1) if the actor has time available for the project. (2) If the actor has the required specific knowledge to perform that role. (3) The project leader's experience with the actor and (4) the proximity (distance) to the project leader. The first boundary rule (B1) can therefore be defined as: There are experts for every position within Antea Group. The project leader assigns these experts based on specialized knowledge, availability, experience and proximity. Whether the actor has affinity, knowledge and/ or experience with circular design is not one of the criteria. This can potentially cause a mismatch of required circular knowledge and provided circular knowledge in the project team. Furthermore, a specific circularity expert only joins the project team if tasks related to this position are included in the scope. This is illustrated with a quote from the contract consultant:

"The sustainability consultant does get involved from time to time, but if sustainability is not asked for in the client request, we are not going to involve that actor ourselves." – Contract consultant HvT.

Actors perform tasks corresponding to their position. They, therefore, enter the project team as soon as their first task starts and exit when their final task has been fulfilled. The actor then moves on to other projects. (B2) An actor enters the project team at the moment he/ she starts contributing towards the project. And (B3) An actor leaves the project team as soon as his/ her specific tasks are completed. This impedes experts to influence project decisions at times he/ she is not involved. For example, in Almen and HvT, the sustainability expert was not involved in setting the scope of the project:

"In the case of Almen and HvT, the sustainability consultant joined the project too late because the design was already (almost) finished. The only thing you can do is to make a calculation based on that design. I believe a sustainability consultant should be present from the start of the project discussing the strategy with the project leader to prevent limiting opportunities through a limited scope." - Sustainability consultant N631, HvT.

In the N631 case, the opposite happened. The sustainability consultant had been involved from the beginning but had fulfilled his duties in the conditioning phase and left the project. As a result, he could not check whether his contribution was included in later steps:

"For the N631 I organised an Ambitionweb session I examined the chances brought up during the session and drafted a report detailing the pros and cons of the measures and advised on what measures to pursue. That, officially, is where my position ends, but I do feel responsible that those measures are actually implemented. Nevertheless, because of other projects, I did not manage to do so. Leading to no real follow-up on those measures." – Sustainability consultant N631, HvT.

Table 5 - Identified boundary rules in the cases.

ID	Identified boundary rules	Effect on circularity	Almen	HvT	N631
B1	There are experts for every position within Antea Group. The project leader assigns these experts based on specialized knowledge, availability, experience and proximity.	Affinity or knowledge regarding circularity is not considered. Circularity experts only join projects if that position is included in the scope, causing a potential mismatch of required circular knowledge and provided circular knowledge.	x	x	x
B2	An actor enters the project team at the moment he/ she starts contributing towards the project.	A specific actor can only influence the project once he/ she enters the project team and cannot influence decisions made beforehand.	x	x	x
B3	An actor leaves the project team as soon as his/ her specific tasks are completed.	A specific actor cannot influence the project after he/ she left and can not check how their input is incorporated in later steps.	x	x	x

Position rules

One position rule has been identified and displayed in Table 6. (Po1) Each position has a specific set of tasks and responsibilities. This means that if something related to circularity has to be done, it becomes a task of the sustainability expert. He/ she is the only actor that utilizes circular tools such as ECI calculations. Other positions have their own specialisation and do not incorporate circularity into this even though the sustainability expert expresses the need to:

"Sustainability, and therefore circularity, is regarded as a separate process. It would be beneficial if every discipline included it in their work. But engineers do not consider circularity unless they are asked specifically to do so." - Sustainability consultant N631, HvT.

This method of specialisation seems logical, educating one structural engineer to conduct the structural calculations is more efficient than educating all your staff to be able to do all tasks required.

A downside to this approach is that it creates large gaps in knowledge between the actors. The sustainability consultant and cost engineer have substantial circular knowledge as they are the ones dealing with circularity within projects. Whereas most other interviewees had little knowledge on the topic. The lack of circular knowledge with most interviewees also ensured that the definition of circularity remains vague and is often confused or misinterpreted as being equal to sustainability. For example, the design leader Almen, HvT & N631 that stated:

"My knowledge and experience with circularity is not that much. I actually related circularity as a synonym for sustainability." – Design leader Almen, HvT & N631.

It would be more useful if everyone considers circularity. Multiple looks at a problem yield multiple solutions and every position has a different view on the problem. Also, the tools to express the circular impact such as the ECI calculation in DuboCalc are the responsibility of cost engineers and sustainability consultants. Whereas designers could also utilize them for examining the environmental impact. This does not happen yet, so the ECI calculation always takes place after designing and not during which allows for adjusting the design.

Table 6 - Identified position rules in the cases.

ID	Identified position rule	Effect on circularity	Almen	HvT	N631
Po1	Each position has a specific set of tasks and responsibilities.	Only the sustainability consultant considers circularity and utilizes circular tools such as ECI calculations. Other positions do not incorporate circularity into their tasks. If this position is not included in the scope, circularity is not considered.	x	x	x

Choice rules

One choice rule was identified from the case studies and is presented in Table 7. As established in the boundary and position rules above, every position has specialised knowledge corresponding to the set of tasks to be executed. While executing these tasks, several choices have to be made. Most of these are made subconsciously as these actors have developed strong working routines. This is illustrated by the Project leader saying:

"The traditional view on construction is strong. Just follow the guidelines and create a concrete structure without considering different materials. We have been doing this for 50 years, why should we change?" – Project leader Almen, HvT, N631.

The actors, therefore, mainly base their decisions (both consciously and subconsciously) on criteria they are aware of. Resulting in the choice rule: (C1) Positions can only incorporate criteria into their choices that they are aware of. As the traditional view on construction is strong, circularity often is not one of the criteria that actors are aware of and therefore, not incorporated into the process. After all, circular knowledge lies with the positions that have specific circular tasks and, therefore, hardly with the other positions. As circular opportunities are not recognised, they cannot be incorporated. A designer and a structural engineer explain this lack of awareness:

"I believe that the general knowledge regarding circularity is present in our division, but the specific knowledge on how to signalise circular opportunities is lacking." – Structural engineer Almen N631.

"I do not have that much experience with circular design and corresponding possibilities. That knowledge potentially is present at Antea Group but is not being used that much." – Designer HvT.

So even though a general understanding of the concept of circularity is slowly emerging, position-specific know-how seems to be lacking. Though both the designer and structural engineer have ideas to improve this:

"We do not have the tools that allow us to calculate and compare different designs with different materials. There are no guiding numbers or rules of thumb for that yet. So, we stick to the traditional approach. I miss the knowledge and tools to see what things we can tweak and what the effects then are." – Structural Engineer Almen, N631.

"I think there is too little knowledge of the diverse types of materials and what the comparative advantages of these materials are. For example, comparing wood to steel and concrete." – Designer HvT.

The sustainability consultant is not involved in everything and can therefore only spot part of the opportunities. other actors could spot further opportunities were they aware of ways to incorporate circularity into projects. A project leader could, for example, take stock of existing materials during a site visit to assess whether parts of them could be reused and an ecologist could instead of researching the current status of the flora and fauna investigate the opportunities to contribute to a richer biodiversity. This does require a change in scope for the conditioning studies.

Table 7 - Identified choice rules in the cases.

ID	Identified choice rule	Effect on circularity	Almen	HvT	N631
C1	Positions can only incorporate criteria into their choices that they are aware of.	Incorporating circular solutions is limited by unawareness among both Antea Group and clients. If opportunities are not recognised, they cannot be incorporated.	x	x	x

Information rules

Information rules dictate how information is shared in design teams. The four found rules are shown in Table 8. The SRS can be regarded as a vital information-sharing product. It literally states the requirements that each actor has to fulfil in a product. It also forms the basis for the verification of the products before handover. System requirements originate from customer requirements as well as design rules and guidelines. In general, the contact between the client and the design team is managed through the project leader and design leader, making them the source of client information for the rest of the design team.

"The input I require predominantly comes to me through the design leader. The input is all kinds of requirements and boundary conditions originating from the client." – Designer HvT.

This makes the first two information rules to be defined as: (I1) Project leader and design leader consult with the client and serve as a source of client information to the rest of the project team. And: (I2) Formal information sharing is done through system requirements.

Delving deeper into the circular requirements, two things stood out. The first one is that, unlike Almen and HvT, the N631 has circular requirements included in the system requirement specification. This makes sense considering that circularity was not included in both the Almen and HvT projects at the moment of creating a SRS. The result, however, was that the design team developed a design without considering circularity. As explained by the structural engineer:

"We have not been asked to consider circularity while designing. Therefore, it had not occurred to me to include it in the design process. It is not common to include circularity in preliminary design calculations." – Structural engineer HvT.

A third information rule is defined as: (I4) The SRS serves as input for the design to be developed. Another aspect that stood out is that the circular requirements that have been included were not formulated SMART (Specific, Measurable, Acceptable, Realistic & Time-related). Some examples:

"The system should be developed as a sustainable system" – Program of requirements N631.

"The system should use sustainable materials and apply techniques that minimise material use." – Program of requirements HvT.

When asking the contract consultant and design leader about these requirements, they state that it is difficult to make these requirements SMART. On the one hand, because specific circular knowledge is lacking to make them more concrete:

"You can see that some sustainable requirements do end up in a contract, but they are quite general. Nobody knows how to make them more specific. Because they are not SMART, people cannot do anything with it." -Contract consultant HvT.

And on the other hand, because that means that the decision-makers have to decide how to apply circularity/ sustainability in the project. In all three cases, these decisions have been made late into the design phase or even after. This prevented the requirements to become SMART and therefore prevented the design team to include these requirements in their work. Resulting in the fourth information rule: (I4) Not all system requirements have to be defined SMART. Not SMART requirements provide challenges later on in the project as they are difficult to design, verify and validate.

Table 8 - Identified Information rules in the cases.

ID	Identified information rules	Effect on circularity	Almen	HvT	N631
I1	Project leader and design leader consult with the client and serve as source of client information to the rest of the project team	Sustainability expert has no direct contact with the client and therefore depends on others to discuss circularity with the client.	x	x	x
I2	Formal information sharing is done through system requirements.	The design only incorporates requirements from the system requirements. If circularity is not part of this, it is not included.	x	x	x
I3	The SRS serves as input for the design to be developed.	If circular requirements are not included, they are not incorporated into the design	x	x	x
I4	Not all system requirements have to be defined SMART.	Circular requirements, if included, are not SMART. This provides a challenge to incorporate them as it is difficult to design, verify and validate not SMART requirements.	x	x	x

Aggregation rules

Aggregation rules entail how decisions are made in an action arena. Two aggregation rules have been identified. These are shown in Table 9. The first aggregation rule (A1) states: The decision-making power lies with the client. Antea Group can only provide advice. The design team, therefore, cannot make major decisions. They can only provide the client with proper information on which to base their choices.

"I do not make circular decisions, I leave that to the clients. As a consultancy, you can give advice but you cannot make the choice." – Design leader Almen, HvT, N631.

"Antea Group can only advice, we do not choose. We can provide sustainable advice, for example in a multiple variant study where we can write that in terms of sustainability variant x scores highest and in case of cost efficiency variant y scores best." – Cost engineer Almen, HvT, N631, ECI calculator Almen.

The cost engineer explains that Antea Group could provide sustainable advice, for example by providing a comparison between a traditional variant and a sustainable variant. The issue, however, is that the client has to decide to allocate money and time for Antea Group to investigate these alternatives. As Antea Group has no decision-making power, it depends on the client's choice to add circularity to the scope or not.

A second aggregation rule relates to the perceived cost of change and is stated as: (A2) The perceived cost of change is high, it is difficult to revise previously made decisions. Going back on a decision implies additional work resulting in delays and more costs. The implication on circularity is that, if circularity is only brought up late in the project, which in two of the three cases happened, many decisions have already been made. The scope in which circular solutions can be created therefore is smaller. In the cases of Almen and HvT this happened. Because circularity had been brought up so late in the process, no major design changes could be made as explained by the designer and project leader of HvT:

"Maybe that was an impediment to the underpasses. We were already so far into the design that it proved difficult to do something with the structure anymore." – Designer HvT.

"If you consider HvT, the inclusion of sustainability felt like a "must do." We were asked to include it by the client so we did a sustainability session to see what could be added to improve the sustainability beyond the design itself. Then ideas regarding the surrounding or exterior are brainstormed, the so-called low-hanging fruits." – Project leader Almen, HvT, N631.

It would be too much effort and investment to revise the design. It would also have jeopardised the schedule. Therefore, simple circular solutions were implemented. An ECI calculation afterwards was included without substantial extra costs and lead time as the design did not need to be altered.

Table 9 - Identified aggregation rules in the cases.

ID	Identified aggregation rules	Effect on circularity	Almen	HvT	N631
A1	The decision-making power lies with the client. Antea Group can only provide advice.	The client can determine whether circularity is included in the project, Antea Group cannot.	x	x	x
A2	The perceived cost of change is high, it is difficult to revise previously made decisions.	If circularity is included later in the project, the scope has decreased as it cannot influence previously made decisions.	x	x	x

Payoff rules

Payoff rules regard the perceived costs and benefits of the project. Four payoff rules have been identified and can be found in Table 10 below. The first payoff rule deals with the perception of important criteria. (Pa1) Railroad availability, budget, time and safety are the main project criteria. The objective of the projects was to develop underpasses that are makeable, sober and efficient, not underpasses that sustainable/ circular. Therefore, the importance of circularity got reduced to a *Nice-to-have* status. The interviewees indicated that this substantially influenced their approach to the project. If circularity would have been important, Antea Group would also have been judged on it if the results were less than expected. This hardly happens now. So apparently the client does not value circularity as much as other criteria, so why focus on it? This was evident from the Almen and HvT cases where circularity was just an afterthought. And in the N631 case, despite a lot of effort at the front end, few sustainable measures were applied. The designer explained that this was because the design turned out to be complex and challenging enough on its own due to the many different interfaces and difficult construction phasing. On the other hand, the structural engineer from Almen and N631 explained that he has also been part of a different project in which time was less of a constraint and circularity a more substantial criterion. In that project, the client valued circularity higher resulting in more opportunities to develop a circular design.

Most projects within Antea Group follow a general process leading to the second payoff rule: (Pa2) Antea Group has strong routines related to developing traditional designs. Because of this, having to demonstrate that a circular variant is feasible and comparable requires more lead time and budget. Necessitating some kind of internal or external incentive to be able to develop this variant. If the goal, once again is to produce a makeable design, then you could either develop a design with innovative materials that all need to be assessed and proven feasible or you can use a traditional and already proven material that complies with all guidelines. In most projects, these innovative designs require too much extra work to comply with the goal, scope and criteria of the project. Therefore, circular solutions are only investigated and implemented in the design if they do not add costs and complexity.

As stated above, clients do not consider circularity an important criterion. The benefits of circular solutions seem to be difficult to value as clients and stakeholders have difficulty imagining and quantifying the impact. The sustainability advisor explains:

"The client does not always understand how to include and measure circularity in the projects either, so we could advise the client in that. [...] Lately, I try to focus more on quantifying the impact of circular solutions. Not even a complete investigation, but just a rough estimate of the costs and benefits. I also try to link the benefits to the ambitions of the client. This shows them that these solutions have benefits. [...] Although the client does not demand it, I also include figurative language in my reports. If I only write that a solution saves x tonne CO2, some clients have no idea how big that impact is. That is why I now often describe it as the same as, for example, x number of flights from Amsterdam to Paris. This appeals more to people because they have a better idea of the impact of such a design choice." – Sustainability consultant HvT, N631.

A third payoff rule can be defined as: (Pa3) Clients and stakeholders are good at valuing traditional criteria, but struggle to value new criteria. Resulting in clients and stakeholders that struggle to value circular impact and therefore, do not feel the need to incorporate it. The contract consultant expresses this feeling as well:

"In projects, I often see that we develop a report on ideas on how to include circularity or sustainability in the project, but then it is not used by the client or in a reduced form. The client also has to start feeling the need to do something with it." – Contract Consultant HvT.

If circular tools such as ECI calculations are used. The client (ProRail) provides strict regulations to Antea Group on how to execute these calculations. Both the cost engineer and the sustainability consultant explained that the client of the cases, ProRail, has guidelines on how to conduct ECI calculations. These guidelines state that only the production and construction phases (A1 – A5) have to be included in the calculation. A second thing excluded from the calculations is the current situation. What the contractors will do with the current materials can have a substantial impact on the circularity of the project. Reuse of some components not only decreases the amount of virgin material to be used but might also contribute to sustainability goals such as the reduction of transport. Both interviewees suspect that the reason for doing so is because it is the same for all contractors anyway, they all have to perform the same tasks and therefore there will not be much difference while it is a lot of extra work in the ECI calculation. One of the interviewees stated that to him, it felt a bit like greenwashing, deliberately leaving out certain parts of the project from the environmental impact calculation. An oversight by the client therefore can be that this might be a factor in which a contractor can distinguish itself. As a tenderer, currently, a design that has the lowest ECI score in the construction phase always beats a design that might have a slightly worse ECI score in the construction phase but makes up for that in later phases. The environmental impact during use, maintenance and deconstruction is not deemed important. Therefore, a final payoff rule is described as: (Pa4) The client (ProRail) prescribes strict regulations to Antea Group regarding the undertaking of specific tasks. The effect on circularity is that these regulations complicate the fair comparison between variants.

Table 10 - Identified payoff rules in the cases.

ID	Identified payoff rules	Effect on circularity	Almen	HvT	N631
Pa1	Railroad availability, budget, time and safety are the main project criteria.	Sustainability, including circularity, is valued as a "*Nice-to-have*" not a core criterion	x	x	x
Pa2	Antea Group has strong routines related to developing traditional designs.	Having to demonstrate that a circular variant is feasible and comparable requires more lead time and budget. Therefore, some kind of internal or external incentive is needed.		x	x
Pa3	Clients and stakeholders are good at valuing traditional criteria but struggle to value new criteria.	Clients and stakeholders struggle to value circular impact.		x	x
Pa4	The client (ProRail), prescribes strict regulations to Antea Group regarding the undertaking of specific tasks.	Regulations set by the client (ProRail) for performing ECI calculations complicate the fair comparison between variants.	x	x	

Scope rules

Scope rules affect the scope of the project and therefore the solution space for potential outcomes. Three scope rules were identified and can be seen in Table 11. In general, the scope becomes narrower the further a project progresses as major design decisions are taken early on in the project. The client (ProRail) has a substantial impact on the scope of a project as they present, in the initiation phase, a list of tasks to be completed by Antea Group. The first scope rule, therefore, is stated as: (S1) The client (ProRail) sets the scope of a project by requesting a list of tasks to be completed by Antea Group. Based on this list of tasks, the project leader develops a bid in which he/ she determines what positions to include and when certain tasks need to be executed. Therefore, the scope fundamentally affects which positions are included at what time in the project. Because of routines, the scope of a preliminary design study is set to comply with traditional criteria such as railroad availability, budget and time. Additional criteria are included as side processes such as safety and sustainability/ circularity can be added but are included as side processes, separated and not integrated. The second scope rule, therefore, is defined as: (S2) The scope of a preliminary design study is set to comply with traditional criteria. Additional steps are included to comply with added criteria as side processes. Circularity is only included in the scope of a project if the client indicates a wish to include it in the project (A1). This indicates that the moment of including circularity heavily depends on when the client addresses this wish.

In the N631 project, circularity was included in the scope during the initiation phase, therefore, an Ambitionweb session was scheduled to take place in the conditioning research phase. This session resulted in a list of circular opportunities but few of them actually got implemented into the design. This happened because the only task included in the scope for the sustainability expert was to conduct and report on the Ambitionweb session, he left the project after that (B3). And, since no additional lead time and budget were reserved later on in the project to further investigate and include the opportunities in the design, it was not possible to include circularity in the design.

Circularity was included as an afterthought in the cases of Almen and HvT, as it only became a criterion during the design phase. No budget and lead time to develop circular solutions had been defined in the initiation phase. In Almen, the only feasible way to include circularity was to conduct an ECI calculation on the traditional design. In HvT a lot of effort has been put into reactively developing circular solutions for the three underpasses. Nonetheless, only one idea was implemented. The other ideas either did not improve the overall sustainability of the project or were deemed too difficult to incorporate so late in the design. This resulted in two of the three underpasses only including an ECI calculation similar to Almen. The contract consultant, who aided the project leader during the initiation phase of HvT stated:

"I believe there was the opportunity to include circularity in these projects. But this space was never discussed or created. So, we did not get anything out of it." – Contract consultant HvT.

Should Antea Group have mentioned circularity during the initiation phase, budget and lead time could have been reserved for it. Through which better results could have been achieved.

Although the terms of circularity and sustainability were used interchangeably by the interviewees, the term circularity is used less frequently. This is further illustrated by the fact that the interviewees and sources talk about sustainability sessions and not circularity sessions, sustainability goals and not circular goals, and sustainability requirements instead of circular requirements. Furthermore, in projects, clients never specifically wish for circularity. If circularity is part of the project scope, it is part of the wish for sustainable solutions as the design leader and sustainability consultant explain in the quotes below:

"I rarely encounter questions related to circularity from clients. A question I encounter more often is: What can we do with sustainability in this project? That is a question that gets asked in almost every project." – Design leader Almen, HvT & N631.

"In the N631 project, we specifically collected opportunities for circularity. In most projects, we notice that the client asks for sustainability in which circularity is a theme. But there are many other themes related to sustainability. Some can be achieved through similar measures, but some measures are contradictory. [...] An Ambitionweb session has eleven themes and you, together with the stakeholders can decide which themes are relevant to the specific project. Circularity is nearly always included as one of the important themes." – Sustainability consultant N631, HvT.

The traditional scope of a preliminary design study, currently, does not include considering circularity. If added, it is viewed as an additional step and something for a sustainability consultant to investigate. In order to gain substantial results, circularity should be integrated into the process, all positions should consider how to incorporate circularity in their actions. Furthermore, the scope of conditioning studies is limited, Minimising harm to the environment is the only thing considered, not how to improve it. As the design leader mentions:

"For example, an ecologist conducts a field study regarding the flora and fauna existing on site. Their output consists of a piece of advice on how to incorporate the new construction into the current situation without causing harm. An opportunity would be to also include a piece of advice on how to improve the biodiversity on site. This provides the client with tangible opportunities to enhance sustainability." - Design leader Almen, HvT, N631.

A third scope rule can therefore be defined as: (S3) Conditioning studies have a limited scope. The only consideration is how to minimise harm to the environment, not how to improve the environment.

Table 11 - Identified scope rules in the cases.

ID	Identified scope rules	Effect on circularity	Almen	HvT	N631
S1	The scope of a preliminary design study is set to comply with traditional criteria. Additional steps are included to comply with added criteria.	The client (ProRail) then prescribes a set budget for the delivery of a sustainable product. No lead time or budget is reserved in the scope for further research and implementation of the measures identified.	x	x	x
S2	The client (ProRail) sets the scope of a project by requesting a list of tasks to be completed by Antea Group	The scope of a preliminary design study, if it includes circularity at all, includes it as a side process.	x	x	x
S3	Conditioning studies have a limited scope. The only consideration is how to minimise harm to the environment, not how to improve the environment.	Circular opportunities in the conditioning studies are not spotted as the scope does not prescribe them.	x	x	x

5.3. Integrating processes and rules

The project process has been uncovered and visualised in Section 5.1. and the rules were identified and listed in Section 5.2. This section aims to integrate these two visualising which rules influence the project at what point during the process and how these rules influence the generation of circular solutions during the design process. The case of NABO Almen is shown in Figure 13, the NABOs HvT case in Figure 14 and the N631 case in Figure 15.

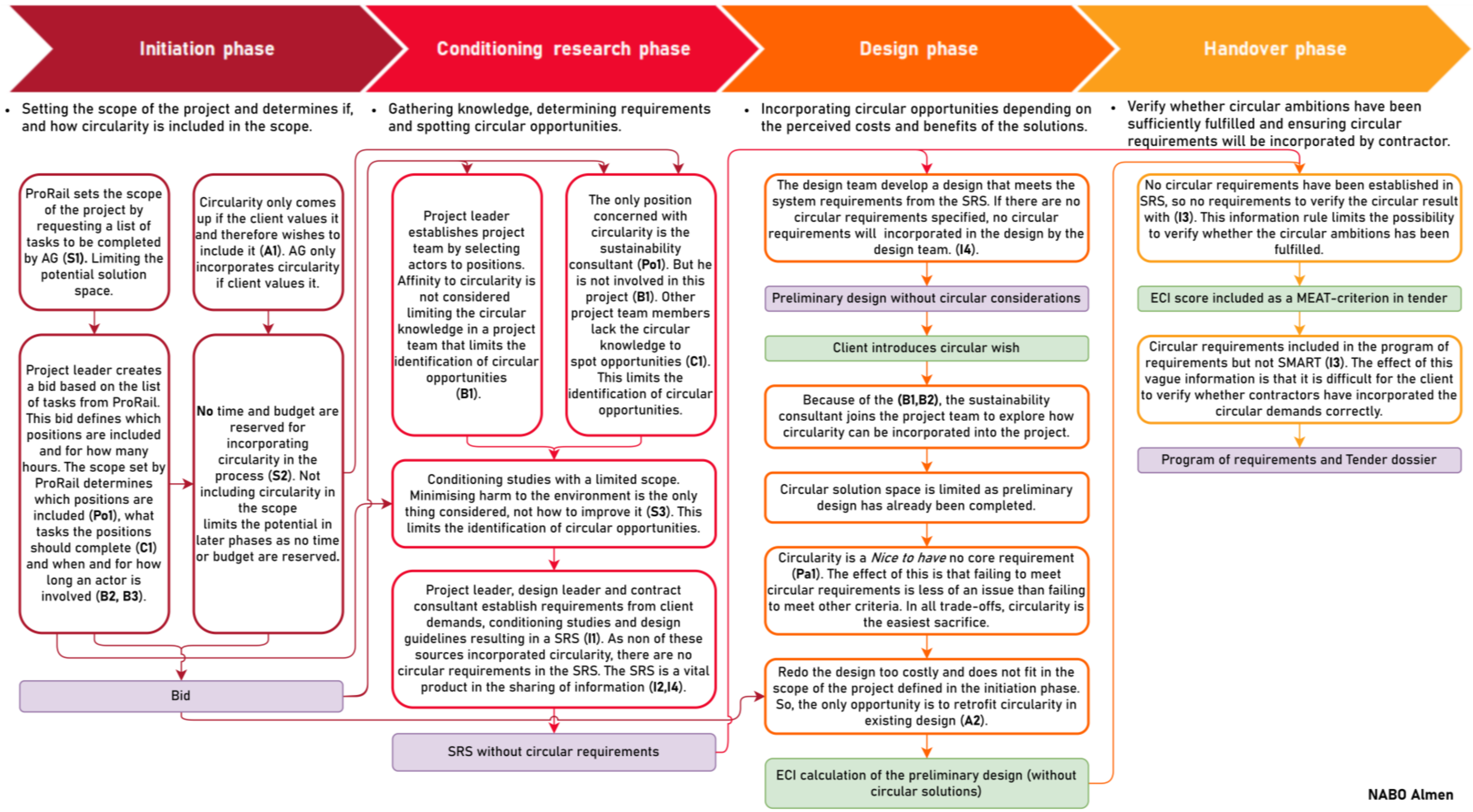

Figure 13 - Visualisation rules in process NABO Almen

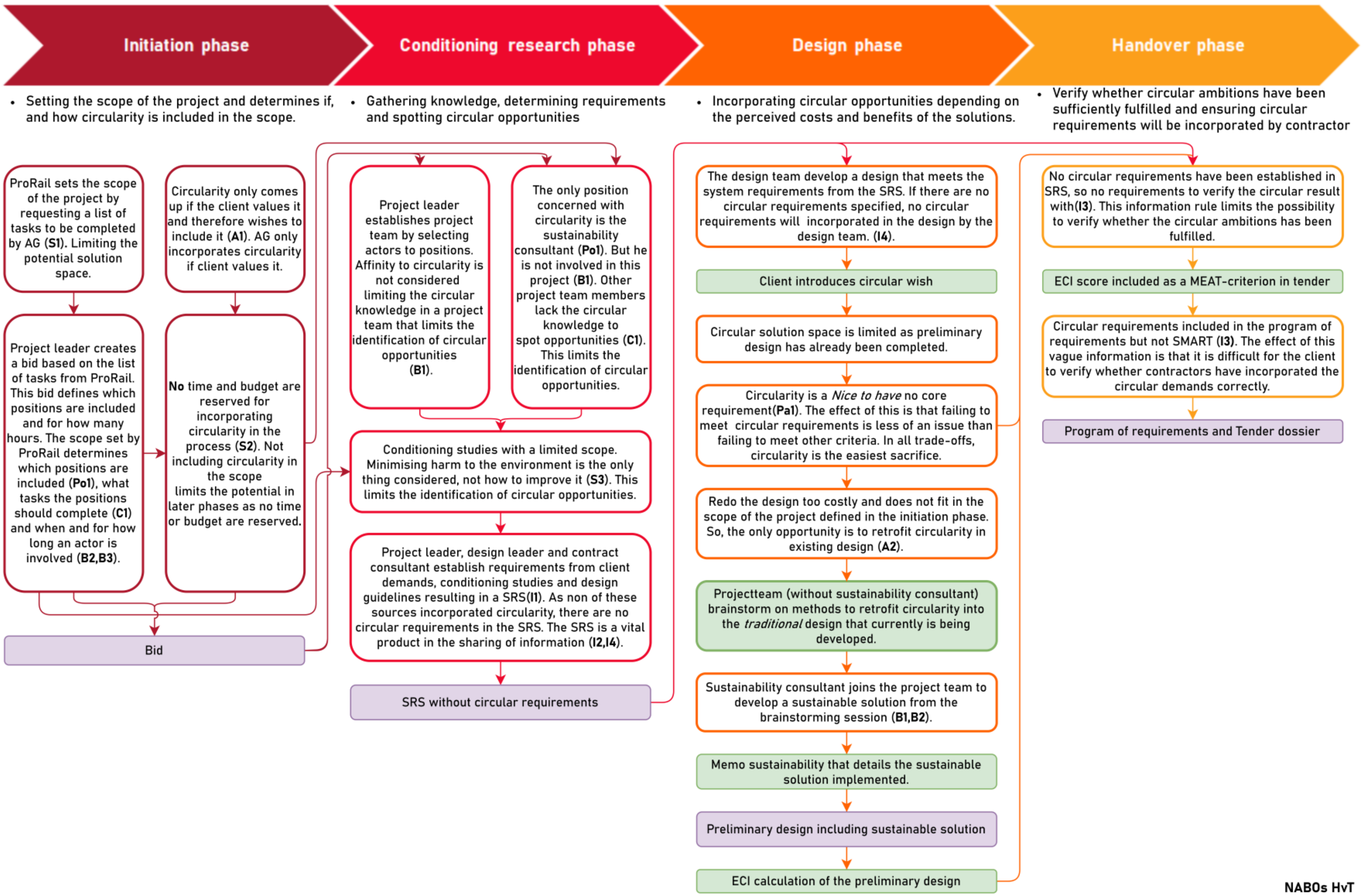

Figure 14 - Visualisation rules in process NABOs HvT

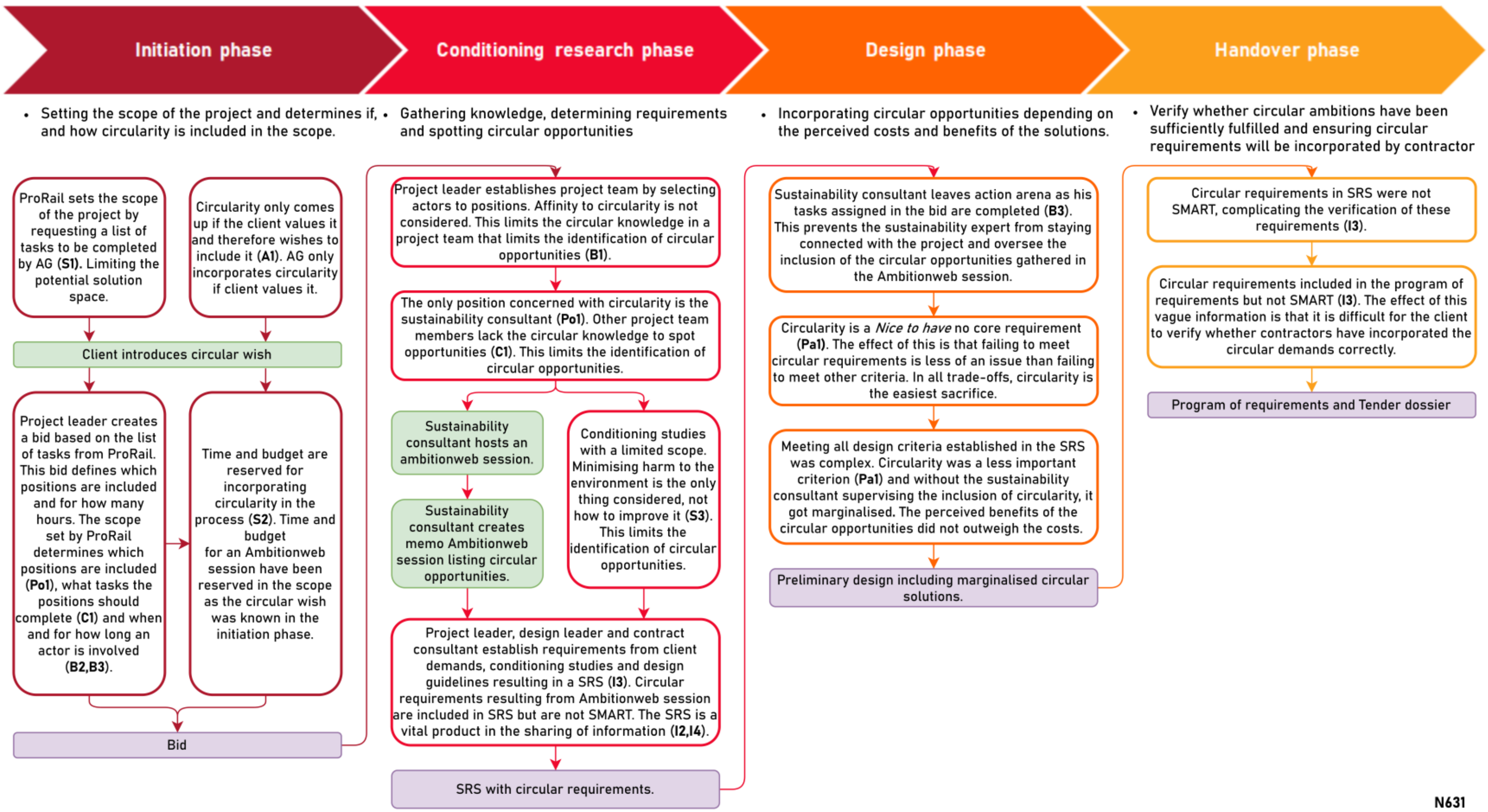

Figure 15 - Visualisation rules in process N631

5.4. Cross-case analysis

Comparing the cases of Almen, HvT and the N631 showed that most rules found were shared across all cases. This stands to reason as the projects compare on most characteristics and actors involved. Shared across these cases, it can be concluded that A1 has a substantial influence on the inclusion of circularity in the projects. Since the client decides, the client chooses the main project criteria (Pa1). This payoff rule influences the scope of the project as the client sets it (S1). This created scope rule S2 as the client values traditional criteria more than circularity. This scope then affects the boundary, position and choice rules as the scope determines which positions to include (Po1), When to include them (B2, B3) and what criteria they should be aware of while conducting their tasks (C1). If circularity is included as a criterion, it is treated as a side process (S1). This causes it to be the sole responsibility of the sustainability consultant (Po1). As circular knowledge is no criterion for selecting the other actors involved in the project (B1) and the general level of circular knowledge in this division still is low, this led to the sustainability consultant becoming the knowledge bearer for circularity. Though, as he was not always directly involved in the project (B2, B3), circular knowledge is not constantly present in the project either. This complicates the inclusion of circularity during the process.

Noticeable is that the rules do not necessarily change from project to project, but the effect of the rules on the process depends on the context of the project. A significant difference is noticed between cases where the client has introduced the concept of circularity during the initiation phase (N631) and where the client has not (Almen, HvT). This difference caused by the client impacts the initiation phase and subsequently all phases afterwards.

During the initiation phase, the client provides a list of tasks to be completed by Antea Group. The project scope is set based on these tasks (S1). In the N631 case, the clients' circular wish was known by Antea Group in the initiation phase. This resulted in the inclusion of circularity in the scope of the project, allowing the inclusion of a sustainability consultant and circular tools such as the Ambitionweb session in the schedule and budget. In Almen and HvT, this wish was not expressed by the client and Antea Group therefore assumed no circular wishes existed. As a consequence, no lead time and budget were reserved in the scope to consider circular solutions.

The effect of the different scopes is noticeable during the conditioning research phase. In Almen and HvT, as circularity was not included in the scope, no position for circularity was included in the project team (Po1) which led to no circular knowledge being present in the project team causing the actors to not consider circularity in their decision-making (C1). This seems logical as, at this point in time, there was no indication that circularity would become a project criterion. As a result, no circular opportunities were spotted during the conditioning research phase(S3). There are some similarities with the N631 case, however, as also in that project the actors did not focus on circularity in their tasks (C1). After all, the sustainability consultant was specifically added to the project to deal with circularity in a side process by conducting an Ambitionweb session (S1, S2, Po1). This sustainability consultant conducted an Ambitionweb session in which circular opportunities were spotted. Though the scope of the project did not reserve time or budget for the sustainability consultant after completing the Ambitionweb session. So, after he finished the memo explaining the opportunities gathered, he had to leave the project team (B3), taking all the circular knowledge with him. This was noticed during the development of the SRS in which the contract consultant struggled to develop SMART circular requirements. Having circular requirements that are not SMART complicates the incorporation of circularity in further phases as formal information sharing of the system requirements is done with the SRS (I2) and unclear requirements are difficult to implement during the design phase as it is difficult to design and verify whether the design met the circular requirements. The sustainability consultant was no longer involved in the project, which meant the project team could no longer consult him for his circular knowledge.

The reason for not incorporating the circular knowledge for longer in the project team links back again to the low perceived value associated with incorporating circularity in the project (Pa1).

During the design phase, the designer and structural engineer develop solutions that meet the requirements stated in the SRS (I4). In Almen and HvT, the design team was not aware of any circular requirements as they were not included in the SRS. Therefore, a traditional design in which no choices incorporated circularity as a criterion (C1) was developed. As soon as the client indicated a wish to include circularity as one of the criteria during the design phase, the designs were almost completely finished. This reduced the circular impact of the projects. In Almen, this resulted in the inclusion of an ECI requirement in the tender dossier and in HvT, a sustainability brainstorm resulted in a circular solution that could be retrofitted into one of the three underpasses of this project. As well as an ECI requirement for all three underpasses. In the N631 case, circular requirements were included in the SRS and, therefore, considered by the design team (I4). Though, in the design phase, the inclusion of these circular requirements got marginalised. Circularity is regarded as a Nice-to-have criterion and not a core requirement (Pa1). This meant that, even though there were circular requirements stated in the SRS, failing to meet these requirements was considered less of an issue than failing to meet other criteria. As designing a general solution for this project, incorporating all core requirements from the SRS turned out to be rather complex. Implementing the circular requirements became less important. The fact that the sustainability consultant was no longer involved in the project to safeguard the value of the circular requirements did not help either.

In the last phase of the project, some circular requirements were incorporated into the tender dossiers encouraging the contractors to consider this criterion during the development of the final design. This was similar between all three projects as all three tender dossiers included circular requirements. However, the N631 project included most circular requirements. HvT included some circular requirements and Almen had the fewest of the three. Verification of all these requirements will prove to be difficult however as most requirements are not SMART (I3).

As a conclusion to the cross-case analysis, it can be noticed that the relatively late involvement of circularity in the cases of Almen and HvT proved to impede the generation of circular solutions. Because circularity was not included in the scope of the project, it was impossible to still incorporate it properly into the project at the time the circular desire emerged. This impediment did not occur in the N631 case as the client indicated the wish to include circularity during the initiation phase already ensuring it would be included in the scope of the project. As the decision-making power lies with the client and circular knowledge currently is scarce at Antea Group, a wait-and-see attitude emerged within Antea Group in which circularity is not actively discussed if the client does not bring it up. This creates a strong dependency on the client to mention circularity in order to incorporate it into the scope and a lot of unnecessary uncertainty about whether or not to include circularity. All interviewees were under the impression that more significant circular results could have been achieved in the Almen and HvT cases. They indicated the late involvement of circularity as a major impediment to the generation of circular solutions. Even though the N631 case did not suffer from this issue, the interviewees also stated that more significant circular results could have been achieved in this project as well. They indicated the high complexity, combined with the low appraisal of circularity (Pa1), and the limited circular knowledge available within the project (B1, B2, B3) as major impediments in this case. The next session will delve into these findings by comparing them to the literature and providing answers to the two research questions.

6. Discussion & Recommendations

6.1. Discussion

The analysis of the three cases through the IAD framework shows that circularity is a side process and is only included if it is specifically demanded by the client. This ensured that as few working rules as possible had to be adjusted to be able to include circularity in the process and prevented the disruption of familiar routines existing within the teams. These results elaborate on Coenen, Volker & Visscher (2022) and Busse (2018) in which they also concluded that a lack of circular knowledge is a major barrier to the creation of circular solutions. Not disrupting the existing working rules is possible as circularity is not regarded as one of the key criteria, meaning that the extra costs and time required to properly include circularity were not perceived as worth it. This is in line with Coenen, Volker & Visscher (2022), in which they concluded that despite the high legitimacy for circularity, little priority is given to it, and it thus often loses out on traditional criteria. Busse (2018) also found a lack of clarity due to abstract and not SMART objectives as a problem and stated that traditional criteria such as time and budget were valued over innovation and circularity.

The analysis furthermore emphasized the importance of the initiation phase for the successful implementation of circularity within projects. This is in line with other work on this topic. Multiple sources identified the initiation phase to be crucial for the success of circularity in projects. Busse (2018) recommended, based on his research, to consider circularity already at an early project stage. Gerding, Wamelink & Leclercq (2021) argued, based on the results of a multiple case study, that by discussing circularity in the early project stages, the chances of implementing circular solutions are much higher than if this is not the case. Van Amstel & Winkelmolen (2017) expressed that the design freedom decreases the further a project progresses and, therefore, that the potential sustainable impact is greatest when the design freedom is largest. Furthermore, Samenwerkingsverband Duurzaam GWW (2012), Crielaard, Chahboun, & Bakker (2019) and Steenbeeke (2022) all emphasised the importance of the initiation phase in the generation of circular designs.

There is a substantial academic interest in circularity. Though, a lot of research is devoted to consumer products and circular business operations. This research contributes by addressing circularity within the built environment. Even though the IAD-framework has been applied to the construction sector before, the scientific contribution of this research project is that it does not investigate the interactions between different parties in a project but delves into the interactions between actors within a party. This provides in-depth details on the reasoning behind why engineering & consultancy firms make specific decisions on the inclusion of circularity. This research elaborates on the existing knowledge that the initiation phase is vital for the successful inclusion of circularity by explaining its effect in the consequent project phases. This provides insight into why the initiation phase is so important. This research project not only investigates the problem but provides clear recommendations on how to tackle the investigated issues. Furthermore, this research elaborates on the applicability of the IAD-framework itself by showing how rules in one category impact rules in other categories.

Further research can be done by analysing other cases using the same method. As mentioned in Section 4.4., the decision to select similar cases for the cross-case analysis limits the generalisability of the results. Furthermore, the fact that most interviewees participated in multiple projects gave better insights into the differences between projects on the one hand, but on the other hand, the generalisation is based on a select group of workers. Therefore, it is recommended to add extra cases to this research to check if similar results are gathered. Another recommendation is to conduct further research into the implementation of the proposed changes to research which specific tools and know-how should be developed to improve the implementation of circularity as well as test whether the proposed changes had the intended effect.

6.2. Recommendations

The first recommendation is to standardise the circular design process by integrating circular responsibilities into the existing tasks of different positions. This alters the position rule (Po1) and therefore affects choice rule (C1) as making actors incorporate circularity into their tasks and responsibilities makes them aware of circularity as a criterion and therefore makes them consider it while executing their actions. This, furthermore, allows for the generation of specific knowledge regarding what each position needs to be able to include circularity into their tasks. A major prerequisite for applying this is that time must be invested in creating and providing task-specific know-how and tools for actors to engage in circularity. A starting point for the standardisation can be based on the work from Samenwerkingverband Duurzaam GWW (2012) and van Amstel & Winkelmolen (2017) as these seem to be industry standards in the Netherlands. Below four examples of the integration of circularity into the tasks of other positions are explained.

The first, and most important step is to enable the project leaders and project managers to discuss circularity during the initiation phase. This requires a change in scope rule S1 where Antea Group no longer adopts a *Wait-and-see* attitude regarding circularity but actively discusses it even though the client might not bring it up. For them to be able to do so, they have to know what tasks Antea Group can offer to investigate circularity. How much lead time and budget should realistically be reserved for this and mainly, how to express the benefits of including circularity in the scope. As the client can and will always have the decision-making power (A1), the project leader and project manager could try to convince the client of the added benefit of including circularity in the scope. This can lead to a change in payoff rule Pa1, in which the client sees the added benefit of circularity and includes it in the scope (changing S1 and S2).

In the second phase (the conditioning research and system engineering phase), circular ambitions should be specified and opportunities should be spotted and researched (van Amstel & Winkelmolen, 2017). An Ambitionweb session should be conducted to define the circular ambition in the project. To be able to spot corresponding circular opportunities, the scope of the conditioning studies (S3) should be adjusted to incorporate spotting circular opportunities. To be able to do so, the actors executing the conditioning research should be provided tools and know-how on how to spot these opportunities. Once a list of opportunities is gathered, the sustainability consultant should conduct a follow-up session on the Ambitionweb session in which the opportunities are discussed with the client/ stakeholders and a decision will be made on which concrete opportunities to pursue. To effectively do so, some kind of quantification of the costs and benefits of each opportunity should be presented.

These chosen opportunities then should be translated into SMART system requirements by the contract consultant. By setting SMART requirements, other project team members can factor these requirements better into their tasks. This can be done by altering information rule I3 into all requirements that have to be defined SMART. Currently, this is not the case as circular requirements tend to remain vague. Three reasons for this resulted from the research. The first one is that the contract requirement lacks the know-how on how to make these requirements SMART. This can be solved by discussing the requirement with the sustainability consultant and collaboratively developing these requirements. The second one is that the client has not yet made up their mind about which circular requirement to pursue. This is no longer possible as the second session with the sustainability consultant intends to decide on what circular goals to pursue prior to the development of an SRS. The third one is that circular requirements are intentionally left vague so that cannot become obstacles to the progress of the project. As circularity is regarded as a *Nice-to-have* criterion and not a core criterion (Pa1), these requirements should not add complexity to the project. Though, as this payoff rule has been changed in the initiation phase already, this should not be a valid argument anymore.

By making circular requirements SMART, the design team is better informed on what is required of them to implement in the design. However, extra steps need to be taken in integrating circularity into the design phase. Currently, the only time the circularity of a design is assessed is after the design is finished. This prevents the comparison between variants on circularity or prevents the designer / structural engineer to consider circularity in their tasks. Providing the design team with simple and usable tools such as circular rules-of-thumb or real-time circular score indicators, (see Coenen, Santos, Fennis & Halman (2021) or the Dutch Ministry of Infrastructure and Water Management (2016) for examples), could aid the inclusion of circularity as a criterion during the design phase. However, further research is required into how to ensure the design team actually will use the tools provided as currently, tools such as the circular design principles (Dutch Ministry of Infrastructure and Water Management, 2020) are provided to the design team but rarely incorporated.

In the final phase (development of the program of requirement and tender documents phase), proper verification of the circular goals and evaluation of whether the ambitions set in the conditioning research and system engineering phase have been achieved should take place. This is also the phase in which circular solutions and experiences should be documented and shared within the organisation for others to take inspiration. Successes can be reapplied in other projects and failures can serve as education to prevent them from happening again. Lastly, circular requirements that are put in the tender dossiers for the contractors to incorporate in the creation of the final design should also be SMART to allow for proper verification of these requirements. Perhaps the contract consultant and sustainability consultant should combine forces to pull this off.

Concluding, the level of task-specific know-how regarding circularity in the infrastructure department of Antea Group should be enhanced. This enables the specific positions mentioned above to integrate circularity into their tasks and responsibilities. By doing so, circularity shifts from a side process under the responsibility of the sustainability consultant to an integrated design criterion. This will increase the focus on circularity and creates lead time and budget to better implement it into the working processes. It is noteworthy to mention that although this research focussed on the generation of circular solutions, the data has shown that circularity is one of the goals within the aim to develop sustainable solutions and although circularity was an important factor in all three case projects, other sustainable goals such as energy efficiency, biodiversity or climate adaptation are important considerations too.

7. Conclusion

Two objectives have been defined for this research project. The first research question states: *What working rules contribute to the generation of circular solutions in design projects?* The answer to this question is that eighteen rules have been identified across all seven rule categories. The Aggregation rule A1, stating that the decision-making power lies with the client has a substantial effect on the generation of circular solutions. As the client decides, he sets the scope of the project (S1, S2). The role of circularity in the scope is little as the client in the investigated cases, values traditional criteria higher (Pa1, Pa3). Because of this, it is harder to assess the added value of circularity in a project compared to the value of traditional criteria. As a result, no, or too little extra lead time and budget is included in the project scope during the initiation phase to thoroughly investigate and apply circularity in the projects. This caused the required circular experts not to be involved during the projects (B1, B2, B3) which affects the level of circular knowledge within the project team (Po1) and, therefore, the reasoning criteria on which actors make their choices (C1). It is crucial to incorporate extra lead time and budget for circularity into the project scope as the inclusion of circularity as a criterion requires alteration of existing working rules resulting in a substantial drop in efficiency due to the development of circular knowledge and know-how.

The second research question states: *What can Antea Group alter to their design process to contribute to the generation of circular solutions in design projects?* The answer to this question is that some working rules will have to be adjusted in order to properly integrate circularity into the design process. Most importantly, adjust scope rule S2 to include circularity in the initiation phase by actively discussing the importance of circularity as a criterion in the project during the setting of the scope. Doing so will ensure that more lead time and budget will be reserved for proper incorporation of circularity during the design process and will aid in solving the issues experienced in the cases. Circularity also no longer should be the sole responsibility of one actor. This alters the position rule Po1 and therefore affects choice rule C1 as making actors incorporate circularity into their tasks and responsibilities makes them aware of circularity as a criterion and therefore makes them consider it while executing their actions. To be able to implement these changes, the lack of circular knowledge and task-specific know-how has to be addressed. Actors that will get new circular tasks should be provided and educated with specific tools and information on how to incorporate this new criterion into their tasks as described in the recommendation section above.

References

Anastasiades, K., Blom, J., Buyle, M., & Audenaert, A. (2020, January). Translating the circular economy to bridge construction: Lessons learnt from a critical literature review. *Renewable and Sustainable Energy Reviews*(117), 109522. doi:10.1016/j.rser.2019.109522

Arnoldussen, J., Endhoven, T., Kok, J., Groot, P., Blok, M., & Kamps, M. (2022). *Materiaalstromen in de bouw en infra.* Economisch Instituut voor de Bouw. Amsterdam: Economisch Instituut voor de Bouw. Retrieved from https://www.eib.nl/publicaties/materiaalstromen-in-de-bouw-en-infra/

Becker, M. C. (2005, September). A framework for applying organizational routines in empirical research: linking antecedents, characteristics and performance outcomes of recurrent interaction patterns. *Industrial and Corporate Change, 14*(5), 817-846. doi:10.1093/icc/dth072

Busse, R. (2018). *De Barrières en kansen voor circulaire innovatie in de bouwsector.* [MSc Thesis], Rijksuniversiteit Groningen, Faculteit Ruimtelijke Wetenschappen. Groningen: Rijksuniversiteit Groningen.

Coenen, T. B., Volker, L., & Visscher, K. (2022). *Barrières voor een circulaire infrasector: analyse met het missie-gedreven innovatiesysteem.* Enschede: Universiteit Twente. Retrieved October 19, 2022, from https://research.utwente.nl/en/publications/barriers-to-a-circular-infrastructure-sector-an-analysis-using-th

Coenen, T., Santos, J., Fennis, S., & Halman, J. (2021). Development of a bridge circularity assessment framework to promote resource efficiency in infrastructure projects. *Journal of Industrial Ecology, 25*(2), 288-304. doi:10.1111/jiec.13102

Crielaard, M., Chahboun, L., & Bakker, P. (2019). *Verdiepende handreikingen Circulaire Economie voor MIRT-projecten.* The Ministry of Infrastructure and Water Management, Rijkswaterstaat. The Hague: The Dutch Ministry of Infrastructure and Water Management. Retrieved from https://leerplatformmirt.nl/over-mirt/handreikingen/handreikingen-verduurzaming-mirt/

de Graaf, R. (2019). *Handbook Systems Engineering in the Construction Industry.*

Duenk, M. (2019). *Improving Smart Mobility implementation in the Netherlands through institutional design - A case study to the Dutch Smart Mobility-programme SmartwayZ.NL.* [MSc Thesis], Rijksuniversiteit Groningen, Faculty of Spatial Sciences. Groningen: Rijksuniversiteit Groningen. Retrieved from https://frw.studenttheses.ub.rug.nl/2734/

Dutch Ministry of Infrastructure and Water Management. (2016). *Handreiking Aanpak Duurzaam GWW.* Den Haag: Ministry of Infrastructure and Water Management. Retrieved from https://www.duurzaamgww.nl/documenten/67-aanpak-duurzaam-gww

Dutch Ministry of Infrastructure and Water Management. (2016). *Nederland circulair in 2050.* Ministry of Infrastructure and Water Management. The Hague: Ministry of Infrastructure and Water Management. Retrieved October 6, 2022, from https://www.rijksoverheid.nl/documenten/rapporten/2016/09/14/bijlage-1-nederland-circulair-in-2050

Dutch Ministry of Infrastructure and Water Management. (2020). *Circulaire ontwerpprincipes [Factsheet].* Rijkswaterstaat. Utrecht: Rijkswaterstaat. Retrieved October 19, 2022, from https://puc.overheid.nl/doc/PUC_166723_31

Eberhardt, L. C., Birkved, M., & Birgisdottir, H. (2022, March 4). Building design and construction strategies for a circular economy. *Architectural Engineering and Design Management, 18*(2), 93-113. doi:10.1080/17452007.2020.1781588

Eisenhardt, K. M., & Graebner, M. E. (2007). Theory Building from Cases: Opportunities and Challenges. *The Academy of Management Journal, 50*(1), 25-32. Retrieved November 17, 2022, from http://www.jstor.org/stable/20159839

Engeström, Y. (2000, July 1). Activity theory as a framework for analyzing and redesigning work. *Ergonomics, 43*(7), 960-974. doi:10.1080/001401300409143

Fewings, P., & Henjewele, C. (2019). *Construction project management: an integrated approach* (3rd ed.). London: Routledge.

Frielink, M. (n.d.). *De Sustainable Development Goals (SDG) waar wij aan werken*. Retrieved October 13, 2022, from anteagroup.nl: https://anteagroup.nl/duurzaamheid/sustainable-development-goals-sdg-waar-wij-aan-werken

Gerding, D. P., Wamelink, H., & Leclercq, E. M. (2021, June 3). Implementing circularity in the construction process: a case study examining the reorganization of multi-actor environment and the decision-making process. *Construction Management and Economics, 39*(7), 617-635. doi:10.1080/01446193.2021.1934885

Gorgolewski, M. (2008, March 28). Designing with reused building components: some challenges. *Building Research & Information, 36*(2), 175-188. doi:10.1080/09613210701559499

Hanemaaijer, A., Kishna, M., Brink, H., Koch, J., Prins, A. G., & Rood, T. (2021). *Integrale Circulaire Economie Rapportage 2021.* PBL Planbureau voor de Leefomgeving. The Hague: PBL. Retrieved from https://www.pbl.nl/publicaties/integrale-circulaire-economie-rapportage-2021

Hanemaaijer, A., Kishna, M., Koch, J., Prins, A. G., & Wilting, H. (2021). *Mogelijke doelen voor een circulaire economie.* PBL. The Hague: PBL. Retrieved October 19, 2022, from https://www.pbl.nl/publicaties/mogelijke-doelen-voor-een-circulaire-economie

Hart, J., Adams, K., Giesekam, J., Tingley, D. D., & Pomponi, F. (2019). Barriers and drivers in a circular economy: the case of the built environment. *Procedia CIRP, 80*, 619-624. doi:10.1016/j.procir.2018.12.015

Hodgson, G. M. (2006). What Are Institutions? *Journal of Economic Issues, 40*(1), 1-25. doi:10.1080/00213624.2006.11506879

Kirchherr, J., Reike, D., & Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, Conservation and Recycling, 127*, 221-232. doi:10.1016/j.resconrec.2017.09.005

Lansink, A. (2018). Challenging Changes - Connecting Waste Hierarchy and Circular Economy. *Waste Management and Research, 36*(10), 872. doi:10.1177/0734242X18795600

Leendertse, W., Hendriksen, J., & Kerkhofs, S. (2018). Introducing the circular economy in road infrastructure development. Challenges and dilemmas in designing circular roads. *7th Transport Research Arena TRA 2018.* Vienna: Zenodo. doi:10.5281/zenodo.1441013

Munaro, M. R., Tavares, S. F., & Bragança, L. (2020, June 1). Towards circular and more sustainable buildings: A systematic literature review on the circular economy in the built environment. *Journal of Cleaner Production, 260*, 121134. doi:10.1016/j.jclepro.2020.121134

Neef, R., Busscher, T., Verweij, S., & Arts, J. (2022). How rule directions influence actors to achieve collective action: an analysis of Dutch collective infrastructure decision-making. *European Planning Studies*, 1-22. doi:10.1080/09654313.2022.2085030

Oosterloo, S., Jansen, M., & Kuijer, R. (2022). *Procedure derdenwerk ProRail.* ProRail BV. Utrecht: ProRail BV. Retrieved April 21, 2023, from https://www.prorail.nl/siteassets/homepage/samenwerken/overheden/documenten/beschrijving-procedure-derdenwerken.pdf

Ostrom, E. (2005). *Understanding Institutional Diversity.* Princeton, New Jersey, United States of America: Princeton University Press.

Ostrom, E. (2011, February 1). Background on the Institutional Analysis and Development Framework. *Policy Studies Journal, 39*(1), 7-27. doi:10.1111/j.1541-0072.2010.00394.x

Potting, J., Hekkert, M., Worrell, E., & Hanemaaijer, A. (2017). *Circular Economy: Measuring innovation in product chains.* PBL. The Hague: PBL. Retrieved October 6, 2022, from https://www.pbl.nl/en/publications/circular-economy-measuring-innovation-in-product-chains

ProRail BV. (2022, March 24). *R.J. Cammocktunnel geopend*. Retrieved April 12, 2023, from prorail.nl: https://www.prorail.nl/nieuws/r.-j.-cammocktunnel-geopend

ProRail BV. (n.d.). *Onderdoorgang Oosterhoutseweg N631*. Retrieved April 12, 2023, from prorail.nl: https://www.prorail.nl/projecten/rijen-onderdoorgang-oosterhoutseweg

ProRail BV. (n.d.). *Over ons*. Retrieved April 12, 2023, from ProRail.nl: https://www.prorail.nl/over-ons

Rijkswaterstaat. (n.d.). *Projectverloop*. Retrieved April 21, 2023, from Rijkswaterstaat.nl: https://www.rijkswaterstaat.nl/zakelijk/zakendoen-met-rijkswaterstaat/werkwijzen/werkwijze-in-gww/werken-in-projecten/projectverloop

Ruiter, H., De Feijter, F., & Wagensveld, K. (2022). Management Control and Business Model Innovation in the Context of a Circular Economy in the Dutch Construction Industry. *Sustainability, 14*(1), 366. doi:10.3390/su14010366

Samenwerkingsverband Duurzaam GWW. (2012). *Aanpak Duurzaam GWW.* CROW. Retrieved Januari 10, 2023, from https://www.duurzaamgww.nl/aan-de-slag

Steenbeeke, M. (2022). *Integrating Circularity in Initiation Phases: A Case Study of Two Bridge (Re)Construction Projects.* [MSc Thesis], University of Twente, ET: Engineering Technology. Enschede: University of Twente.

Teisman, G. R. (2000, January 17). Models For Research into Decision-MakingProcesses: On Phases, Streams and Decision-Making Rounds. *Public Administration, 78*(4), 937-957. doi:10.1111/1467-9299.00238

The Ellen MacArthur Foundation. (2013). *Towards the Circular Economy Vol.1.* The Ellen MacArthur Foundation. Retrieved April 5, 2021, from https://ellenmacarthurfoundation.org/towards-the-circular-economy-vol-1-an-economic-and-business-rationale-for-an

Transitieteam Circulaire Bouweconomie. (2021). *De inrichting van het basiskamp - Uitvoeringsprogramma 2021-2023.* RVO. Retrieved October 6, 2022, from https://circulairebouweconomie.nl/nieuws/het-uitvoeringsprogramma-2021-2023/

Transitieteam Circulaire Bouweconomie. (2022). *Adviesroute naar een Circulaire Economie voor de Bouw.* Retrieved October 6, 2022, from https://www.rijksoverheid.nl/documenten/rapporten/2022/07/15/bijlage-5-adviesroute-naar-een-circulaire-economie-voor-de-bouw

van Amstel, N., & Winkelmolen, J. (2017). *Kennispaper: Haal eenvoudig het beste uit de Duurzame Bouw.* Delft: SBRCURnet. Retrieved from https://www.duurzaamgww.nl/documenten/85-kennispaper-haal-eenvoudig-het-beste-uit-de-duurzame-bouw

van Heffen, O., & Klok, P. (2000). Institutionalism: state models and policy processes. In O. van Heffen, J. Kickert, & J. Thomassen, *Governance in Modern Society: Effects, Change and Formation of Government Institutions* (pp. 153-177). Dordrecht: Kluwer Academic Publishers.

Yin, R. K. (2003). *Case study research: design and methods* (3rd ed.). Thousand Oaks, California, United States of America: Sage Publications.

20-7-2023

WORKING RULES IN DESIGN PROCESSES ON DEVELOPING CIRCULAR SOLUTIONS

APPENDICES

TIM STEVERING

anteagroup

UNIVERSITY OF TWENTE.

Appendix A: Interview Scheme

Interviewschema

Hallo ik ben Tim Stevering, student Construction Management & Engineering aan de Universiteit Twente. Ik loop afstudeerstage bij Antea Group om onderzoek te doen naar het implementeren van circulaire oplossingen in ontwerpprojecten. Dit onderzoek is bedoeld om inzicht te krijgen in wat Infra kan doen om het gebruik van circulariteit in projecten te verbeteren.

Het doel is om inzicht te krijgen in de (on)geschreven regels die gelden binnen Antea Group en hoe deze het ontwerpen van circulaire oplossingen beïnvloeden. Denk bijvoorbeeld aan: werknemers moeten hun uren verantwoorden per project en het werken volgens het vier-ogen-principe.

De nadruk ligt dus niet op de technische aspecten van de desbetreffende oplossingen, maar op de rol die circulariteit speelde in het ontwerpproces. Bijvoorbeeld de afwegingen waarom bepaalde stappen in het proces op welk moment genomen zijn en wie daarbij betrokken waren. Uw antwoorden op het interview worden geanonimiseerd

Inleidende vragen:

- Heeft u bezwaar tegen het opnemen van dit interview? (Het opnemen dient enkel voor de verwerking van de resultaten, en wordt na het verwerken van de resultaten verwijderd.)
- Wie bent u?

Algemene vragen:

Boundary rules:

1. Aan welke aspecten van dit project heb je meegewerkt?
2. Hoe wordt bepaald wie er deel worden van een projectteam?
3. Zou u andere personen of personen op andere momenten betrekken bij het project om meer circulaire oplossingen te creëren? Zo ja, waarom is dit in deze projecten niet gedaan?

Position rules:

4. Hoe wordt bepaald welke rollen er zijn en met wat die rollen zich bezighouden?
5. Welke verantwoordelijkheden draagt u in dit project?
6. Welke output produceert u? en wat wordt er met die output gedaan? (Wordt die output getoetst aan duurzaamheid)?

Choice rules:

7. Hoe kunt u circulariteit toepassen in uw werkzaamheden?
8. Hoe heeft u dit in dit project toegepast?
9. Wat limiteert u in het bezig zijn met circulariteit binnen het project?
10. Zou u achteraf met andere acties invullen hebben gegeven aan de circulaire vraag?

Information rules:

11. Wat is uw kennis en ervaring met circulariteit?
12. Welke informatie heeft u nodig om circulariteit toe te kunnen passen in uw werkzaamheden? (Hoe komt u aan die kennis?)
13. Waarom zijn bepaalde duurzaamheids-/ circulaire stappen op specifiek die momenten in het proces gedaan?
14. Hoe heeft dit het creëren van duurzame/ circulaire oplossingen beïnvloed?

Aggregation rules:

15. Hoe worden besluiten genomen in dit project, wie neemt welke beslissingen?
16. Welke beslissingsruimte heeft u binnen dit project?

Payoff rules:

17. Welke criteria spelen een rol bij de besluitvorming binnen dit project?
18. Hoe kan circulariteit een van de doelen in het project worden?
19. Hoe verhoudt de aandacht voor circulariteit zich tot andere doelen in de projecten (bijvoorbeeld veiligheid of innovatie)? En welke rol speelt de opdrachtgever hierin?
20. Wat zijn de grootste risico's voor Antea Group in dit project?
21. Heeft u specifieke circulaire afwegingen gemaakt in dit project? Zo ja, licht deze toe, zo nee, waarom niet?

Scope rules:

22. Hoeveel ruimte was er om circulariteit mee te nemen in dit project?
23. Wat belemmerd de mogelijkheden om circulariteit mee te nemen in het project?
24. Hoe beïnvloed de manier van werken binnen dit project de creatie van circulaire oplossingen?

Afsluiting:

- Heeft u nog ideeën, observaties of mededelingen die volgens u meegenomen moeten worden in dit onderzoek?
- Heeft u verder nog vragen over dit onderzoek?

Bedankt voor uw tijd.

Appendix B: Interview information

Table 12 - Details of the interviews

Inter-view	Position Almen	Position HvT	Position N631	Date	Location
1		ECI calculator	Sustainability consultant	27-02-2023 (09:30 – 11:00)	Antea Group office Deventer
2		Structural engineer		27-02-2023 (13:00 -14:00)	Antea Group office Deventer
3	Structural engineer		Structural engineer	28-02-2023 (10:00 – 11:00)	Antea Group office Deventer
4	Cost engineer and ECI calculator	Cost engineer	Cost engineer	02-03-2023 (9:00 – 10:30)	MS teams
5	Designer		Designer	02-03-2023 (13:00 – 14:00)	MS teams
6		Designer		07-03-2023 (09:00 – 10:00)	Antea Group office Deventer
7			Project manager	08-03-2023 (09:00 – 10:00)	MS teams
8		Design leader and Contract consultant		10-03-2023 (09:00 – 10:00)	Antea Group office Deventer
9	Design leader, project controller and contract consultant	Project controller	Design leader, project controller, contract consultant	10-03-2023 (13:00 – 14:30)	Antea Group office Deventer
10	Project leader	Project leader	Project leader	16-03-2023 (10:00 – 11:00)	Antea Group office Deventer

Appendix C: Organisational charts.

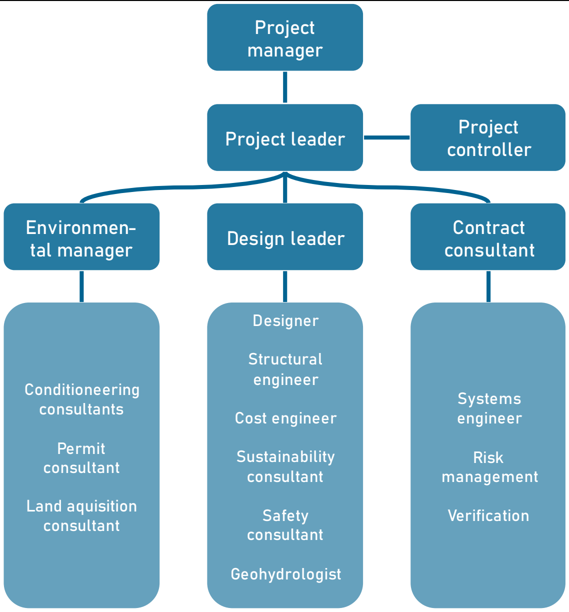

Figure 16 - Organisation chart rail engineering projects

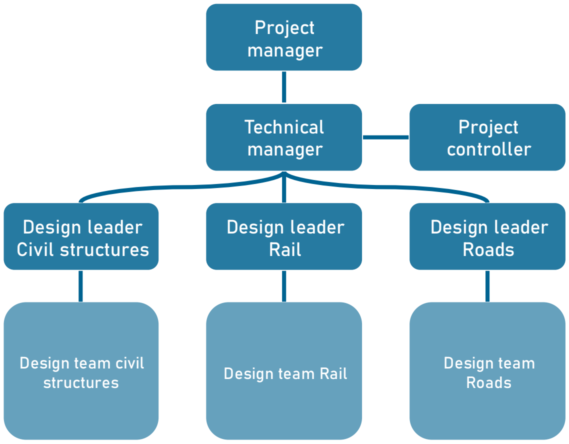

Figure 17 - Organisation chart multidisciplinary projects

Appendix D: Timelines case projects.

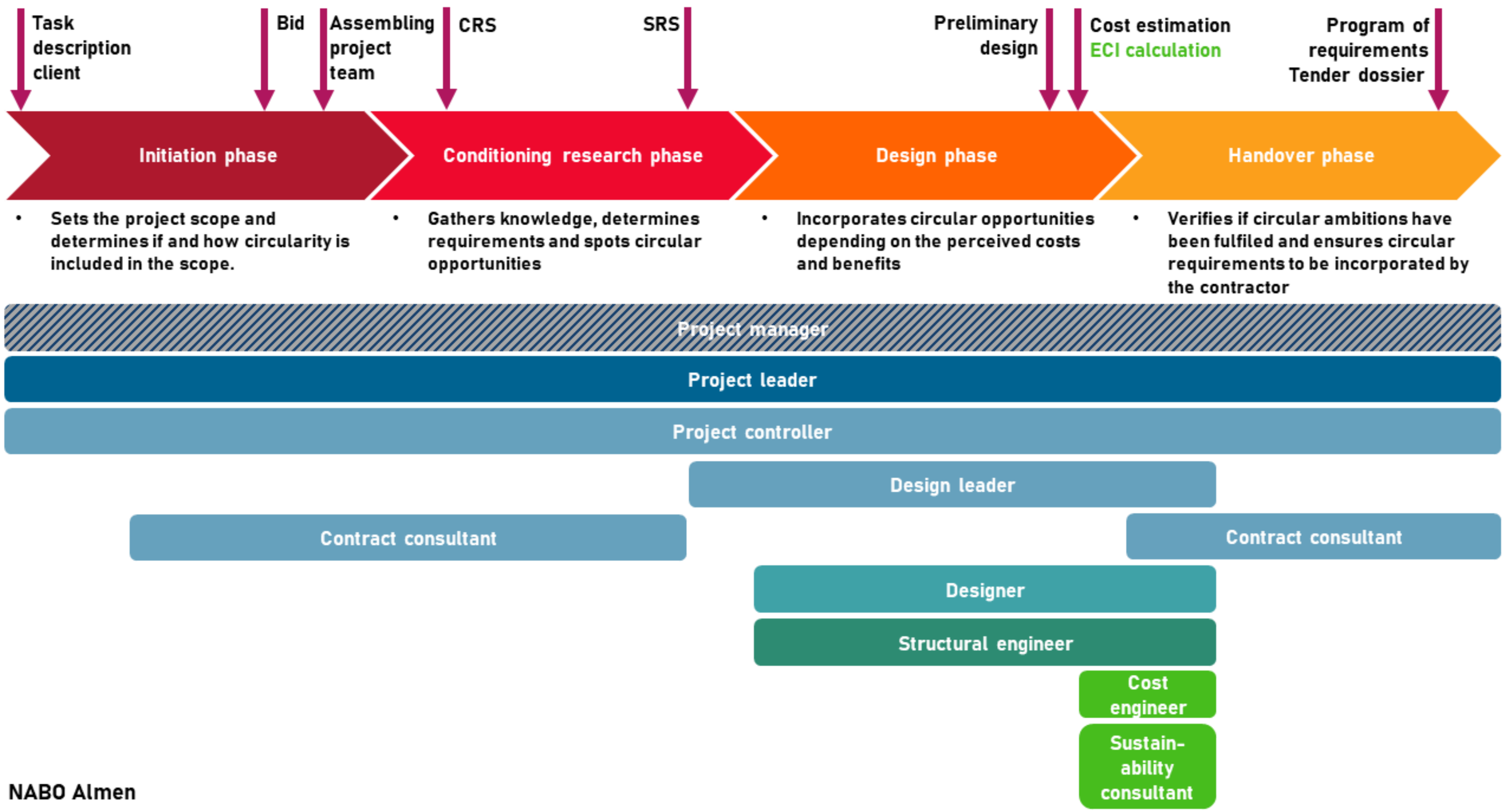

Figure 18 - Timeline NABO Almen

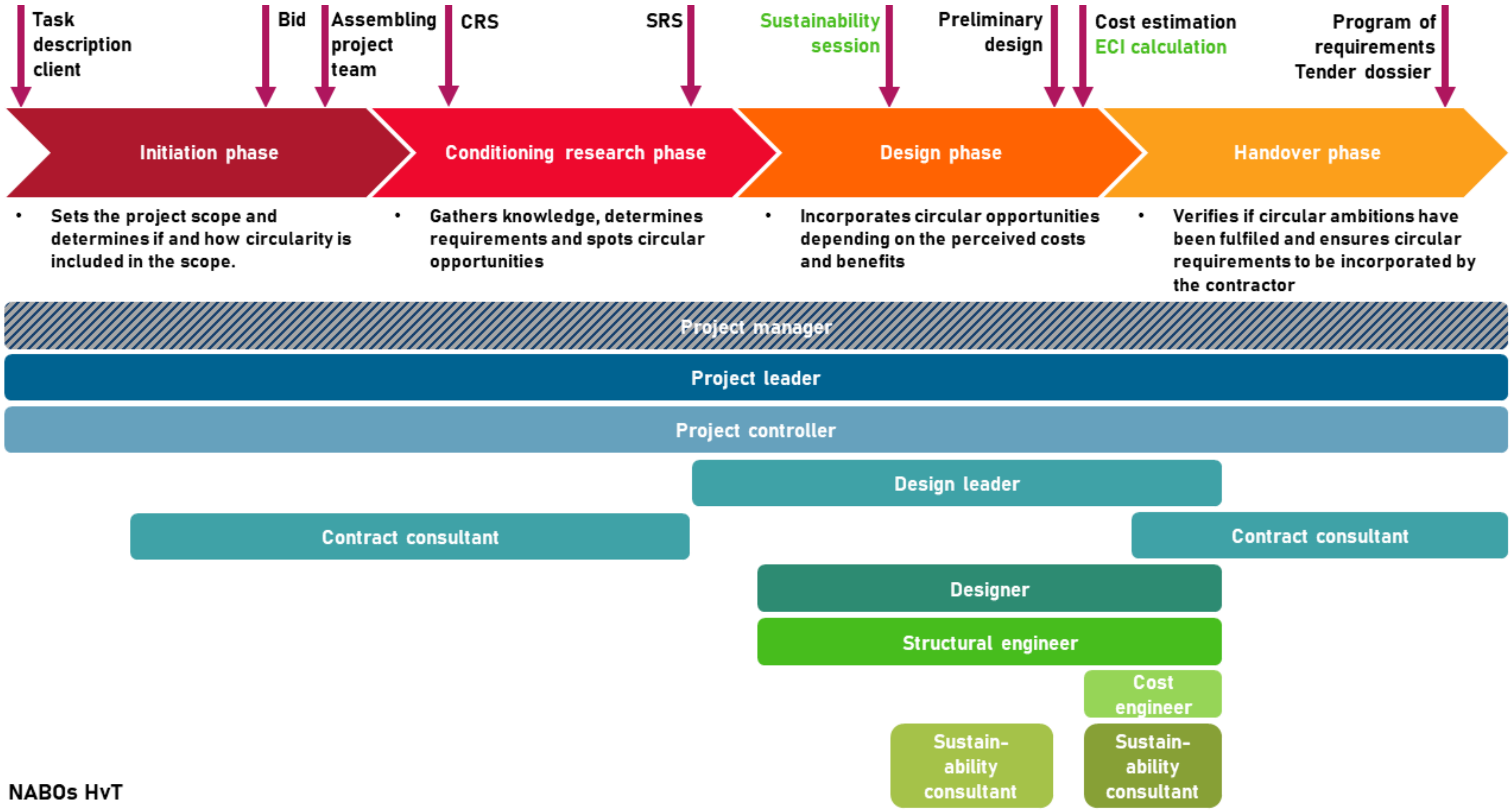

Figure 19 - Timeline NABOs HvT

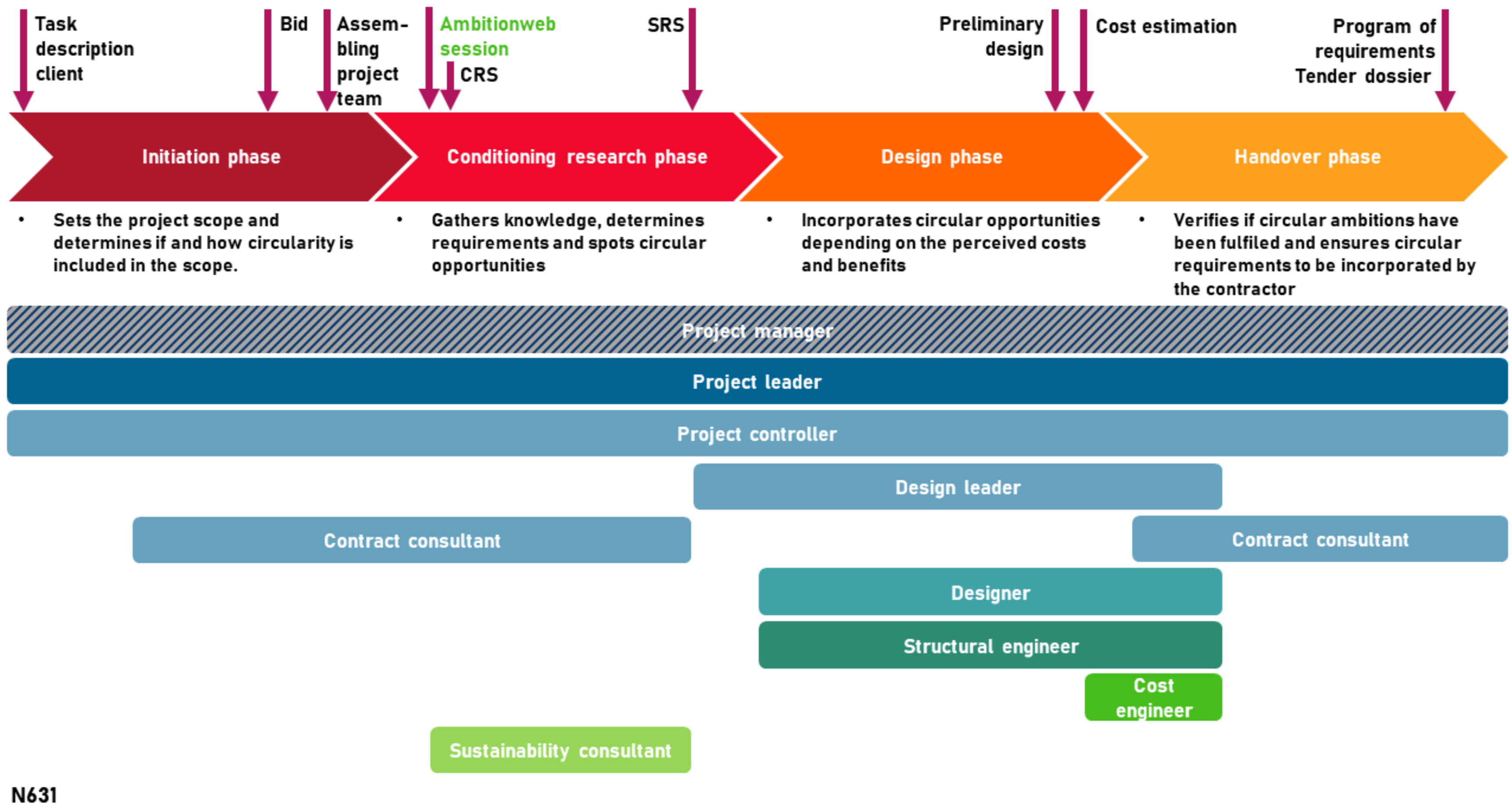

Figure 20 - Timeline underpass N631