Tunnel Visions on Sustainability

Sustainability aspects and its selection process for road tunnel construction projects

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Executive summary

Since the Brundtland report in 1987, sustainable development appeared on the agenda of every industry. It was defined as: "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". It is of great importance to focus on sustainable development within the construction industry. The construction industry has been enormously important for our quality of life; at the same time it is a major polluting industry and a large-scale consumer of natural resources including fossil fuels. This industry alone accounts for 50% of all global resource use. So far the implementation of sustainable construction projects have primarily focused on buildings, with less attention for infrastructure. Infrastructures however, are certainly not to be neglected in the transition towards a more sustainable society. The negative impact of road tunnels on the environment is even larger than the negative impact of a normal road. The main focus of this research is on the sustainable development of infrastructures and road tunnel construction projects in specific.

Sustainable procurement is a powerful instrument for integrating environmental issues into the procurement process and for achieving sustainability goals. Using the Economically Most Advantageous Tender (EMAT) award mechanism is one way to incorporate sustainability as a key criterion into the procurement process of tunnel construction projects. A framework of EMAT procurement criteria for sustainability in tunnels is needed to ensure that sustainable development becomes integrated in tunnel construction projects. Therefore a framework with such sustainability aspects for road tunnel construction projects has been developed in this MSc thesis research.

The perspective of the Project Delivery Organization (PDO) on sustainable development needs to be clear in order to have a successful procurement process. Unfortunately the client, who makes the strategic decision to undertake the project, is often lacking a clear definition of a sustainable tunnel. To arrive at a sustainable tunnel, first the client needs to define and specify what is meant with a sustainable tunnel so that the PDO and the tenderers have common ground when talking about a sustainable tunnel. To support the Client and PDO in identifying their definition of a sustainable tunnel, existing perspectives on sustainable tunnels will be identified and an approach will be proposed for selecting and ranking relevant sustainability aspects for their specific tunnel project.

The main research question is:

- How to incorporate sustainability into the procurement phase of a road tunnel construction project with regard to sustainability aspects and their selection process?

This research question has been divided into three research sub questions. These sub questions are directly connected to the following three objectives of this thesis.

Objective 1: To create a framework of relevant sustainability aspects, from which the aspects could be used for securing sustainability in the procurement process of tunnel construction projects.

Now a summary of the used method to achieve this objective will be given. The first step in developing a framework with sustainability aspects was to create an inventory of possible aspects. This was developed on the basis of existing sustainability assessment tools, tunnel reference projects, expert interviews and literature. This led to an inventory of 102 aspects in total. As a next step, this inventory was filtered on the following criteria: occurrence in literature, variety of sources and level of detail. As a final filter, aspects with ambiguous names and low scoring aspects were merged. An initial framework of 35 aspects was developed as a result of this filtering process. A linguist validated the definitions of these aspects for use in the Q-methodology. During the research 26 participants, who represent the tunnel construction supply chain, tested the validity of the framework. Based on their comments the initial
framework was adjusted and a final framework, containing 33 aspects, could be established. The final framework of sustainability aspects for road tunnel construction projects is pictured below;

**Final framework of sustainability aspects**

![Diagram of sustainability aspects]

**Objective 2: To identify the existing perspectives on sustainable road tunnels.**

The initial framework of aspects was used as a ‘Q-sample’, which is the input for the Q-methodology. The Q-methodology is a method to study subjectivity towards a topic using the Q-sorting technique. In this case the methodology was used to identify existing perspectives towards sustainable tunnels, by having participants rank the defined sustainability aspects from least important to most important. In total 26 participants participated in the research, covering all kinds of positions within the tunnel construction supply chain. The participants performed the Q-sort by ranking the aspects and substantiating their choices. All completed Q-sort questionnaires were used as quantitative data input for a factor analysis. The outcomes of the factor analysis, in combination with the qualitative comments were used to identify perspectives and to construct names and narratives for these four perspectives:

- **The Energy Perspective:** “Minimize energy-use, reduce carbon emissions and ensure efficiency over the project life cycle.”

The Energy perspective assesses the sustainability of tunnels based on *Energy use, Energy efficiency, Long-term design* and *Life cycle cost*. The Energy perspective was shaped by the questionnaires of five participants with an analytical background. Trade-offs between aspects were made with a long-term perspective and materials and energy should be used as efficient as possible. Participants sharing this perspective value aspects that are measurable and quantifiable, such as *CO2 emissions* and *Air quality*. Energy is the most important driver, in terms of quantity (total use) and quality (production method - *Renewable energy* and *Energy efficiency*-). To achieve a sustainable tunnel, an efficiency approach is taken towards all aspects within the construction process. Therefore *Multifunctionality* does not fit within this perspective, since it is questionable if this leads per se to a sustainable tunnel. This perspective would take the following sustainability aspects into account during the procurement process

➢ **The Resilience Perspective: “Optimize functionality and value over the project life cycle.”** Participants sharing the Resilience perspective focus on processes and value systems thinking. The shared belief of holders of this perspective is that a sustainable tunnel should be optimized for its functionality. According to this perspective, Value optimization is about maximizing positive effects and creating added value to the project with an emphasis on process and LCC thinking. This perspective was defined by six participants with a predominant (civil) engineering background who consider optimization problems as interesting challenges. For example, these participants see Multifunctionality as a technical optimization of smart solutions. This group would define a sustainable tunnel as a tunnel that has maximum functionality and value. This perspective would take the following sustainability aspects into account during the procurement process (in order of importance): Life cycle cost, Multifunctionality, Value optimization, Influence on surface area, Functional flexibility and Design for disassembly

➢ **The Social Perspective: “Consider local stakeholders and the direct project environment.”** The Social perspective regards a sustainable tunnel as a tunnel that has been constructed in close cooperation with local stakeholders and with maximum attention for the (changing) project surroundings. The perspective was shared by six participants who had different educational backgrounds, yet were mostly project managers. The latter could clarify the emphasis on sustainability as a people matter. Their core belief is that if stakeholders are involved, they will value and even contribute to the project. Consequently there will be less obstruction to the project, which makes the tunnel construction project more sustainable. Furthermore there should be more functionality to the project than just a road. The project managers explain this as follows: “Budget can only be spent once, it is always smart to combine functions.” This perspective would take the following sustainability aspects into account during the procurement process (in order of importance): Functional flexibility, Local stakeholder involvement, Multifunctionality, Human rights and fair trade, Air quality, Life cycle cost and Value optimization

➢ **The Transition Perspective: “Prevent harmful effects on people and the planet now and on the long-term.”** This perspective, shared by five participants, considers sustainability aspects with impact on the project surroundings; on the people and their environment (planet). ‘A sustainable project is a project without toxics and chemicals and without environmental harms.’ It also considers the effect on people’s health, sight, perception and experience. Sustainability demands an entirely new approach according to the participants that share this perspective. This group looks into the future and within their future there is no room for profit aspects. Sustainability is about re-thinking and re-designing in many ways. Therefore Functional flexibility is viewed as the most important aspect. ‘Let go of the old way, sustainability requires a new approach.’ And this approach is without any harmful future effects on people and planet. This perspective would take the following sustainability aspects into account during the procurement process (in order of importance): Functional flexibility, Influence on surface area, Toxic materials, Renewable energy sources, Visual sustainability and experience, Recycling and re-use and Energy use.

**Objective 3:** To develop an approach that can support clients and PDOs in selecting and ranking sustainability aspects, based on the specific circumstances of the project.

The approach enables the client to select and rank sustainability aspects for their specific project. Based on this, the client can create a clear project-specific definition of a sustainable tunnel. The approach is a workshop. Input for this workshop will be the framework of sustainability aspects developed in this research. The client can organize such a workshop at the start of the project, either within their organization or by inviting all relevant stakeholders. During the workshop participants will rank the sustainability aspects for this specific project. A properly facilitated workshop will yield: an initial aspect ranking, current perspectives within
the organization, consensus and contention aspects. These outcomes can be used as a dialogue support tool and can improve communication between stakeholders and improve decision-making. The advantages of this approach are:

- The sorting process helps to identify the individual opinion on a sustainable tunnel;
- Participants dare to give their own opinion, because they perform the Q-sort questionnaire individually;
- This approach makes sustainability specific and discussable;
- The consensus aspects provide a basis for mutual understanding and can be a way forward through conflict;
- The contention aspects can be used as ground for discussion;
- It generates understanding on the issue and insight about the different perspectives existing within the organization;
- This approach can be used to involve stakeholders and can lead to stakeholder support;
- The Q-questionnaire is broadly applicable since it is understood by as well tunnel technical experts as policy makers as people with little experience and knowledge about the project.

➢ How to incorporate sustainability into the procurement phase of a road tunnel construction project with regard to sustainability aspects and their selection process?

The client can either make direct use of the framework by selecting sustainability aspects for their procurement directly from the framework. The identified current perspectives provide insight in the framework. Or the client can organize a workshop and use the framework as input and the output as a dialogue tool, which supports the client with the selection process.

The framework with 33 sustainability aspects for road tunnel construction projects can be considered as a comprehensive and applicable framework. This framework forms a basic set of sustainability aspects that can be adapted and improved over time by experts and experience. The proposed approach shows the applicability of the framework with sustainability aspects and can support clients and PDO’s in selecting and ranking sustainability aspects for their specific project. The identified perspectives may lead to more understanding on sustainability within the industry by making sustainability more explicit and tangible. Furthermore it can also help individuals to better understand their position towards sustainable tunnels and create more understanding between stakeholders in the tunnel construction supply chain, which may fasten the transition towards a sustainable society.

The most important recommendations for clients of tunnel construction projects are:

➢ Apply the proposed approach as early as possible in the project.
➢ Establish a clear and ambitious definition of a sustainable tunnel based on the selection of sustainability aspects. The developed framework, perspectives and approach can be used to make a selection of sustainability aspects.
➢ Value sustainability significantly as an award criterion to stimulate innovation in the market and to contribute to future project exceeding developments as well.
➢ Operationalize and monitor the selected sustainability aspects in cooperation with experts.
➢ Share experiences with incorporating sustainability in the procurement of a tunnel construction project with other clients and PDOs to contribute to the urgent transition towards a sustainable future.
➢ Implement sustainability in the entire process (EMAT award criteria, minimum requirements, form of contract, operations of own organization etc.) and share experiences to contribute to the transition towards a more sustainable society.
Acknowledgment

This report is the result of my thesis research as part of the master degree Construction, Management & Engineering at Delft, University of Technology.

It was during my bachelor that I went on a student entrepreneur’s trip to Shanghai during the World Expo - Better City, Better Life - when I first became aware of the impact the built environment on the quality of life. Here the need for a more sustainable approach to construction became clear to me. Inspired by the new developments shown at the expo, I felt the desire to contribute to this development. Since then I am continuously looking for opportunities that can improve my knowledge, skills and expertise in this field.

Where my master program provided me a solid understanding of the construction industry, I needed extracurricular activities and electives to learn about sustainable construction. I was very happy to receive an email from professor Marcel Hertogh with the opportunity to perform a research on integrating sustainability in the procurement of tunnel construction projects. Both the topic and the research environment have been an extremely educational and interesting environment to finish my studies.

This research would not have been possible without my graduation committee. First of all, I would like to thank Marcel, for thinking about me when this opportunity arose and for involving me in the expert team of the Rotterdamsebaan. Paul, thank you for providing me the unique opportunity to perform this research within the project team of the Rotterdamsebaan and for your trust when giving me access to your network when I was searching for research participants. Arjan, thank you for sharing your experiences on integrating sustainability into practice and by showing me the ‘higher order learning’ you made me realize that I am making an actual contribution to the developments in this field. Marian, thank you for your continuous constructive feedback and for putting my research into (scientific) perspective. Also thank you for believing in me when I proposed tight research schedules and high ambitions. I want to thank Cynthia Sewbalak for letting me be part of the procurement & contracting team at the Rotterdamsebaan and the entire ‘Roba’ team for the nice working environment in The Hague.

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Enjoy reading!

Darinde Gijzel
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1. Introduction

1.1. The need for sustainable infrastructure development

1.1.1. Climate change and sustainable development

In September 2013 the Intergovernmental Panel on Climate Change (IPCC), a United Nations body, released the Fifth Assessment Report on global warming. This report shows that scientists are more certain than in 2007, when the 4th report was published, that it is “extremely likely” that human activity, e.g. burning fossil fuels and cutting down rainforests, has been the dominant cause of the observed global warming since the 1950s (IPCC, 2013). The report tells us that oceans have warmed up, snow and ice have diminished, sea levels have risen and extreme weather events have become more common. Climate change is a serious threat to humanity.

“To combat climate change and to protect the health of our economies, communities, children and future, decisive global action is needed. Although 200 governments have agreed that the global average temperature increases must be kept below 2 degree Celsius to avoid catastrophic warming, we are on track to hit the worst-case scenario. Nonetheless, research indicates that it is possible to limit warming below the threshold if far reaching action towards sustainable development will be taken” (Suzuki, 2013).

Since the publication of the report “Our Common Future” by the World Commission on Environment and Development, sustainable development has been widely addressed. There are now hundreds of definitions of sustainability available. The often-quoted definition that originates from the report is the following;

"Development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (UNWCED, 1987).

Sustainable development requires action on three fronts: socially (people), environmentally (planet), and economically (profit). Addressing climate change is a shared responsibility that all countries, communities and industries must embrace at all levels by adopting effective policies and actions (ACT Government, 2013). All industries should have a sustainability focus, however some industries can have a greater impact than others. The construction sector accounts for 50% of all global resource use and therefore it is of major importance to focus on sustainable development within the construction industry (CIOB, 2002). In the next section more information on sustainability challenges in the construction industry is given.

1.1.2. Sustainability in the construction sector

The construction industry is of great importance for our quality of life - houses, office buildings, industries, roads, bridges and other infrastructures – it provides shelter, supports education and connectivity. Furthermore this industry is a major generator of jobs (Modular Building Institute, 2010). At the same time the construction industry is a major polluting industry and a large-scale consumer of natural resources and fossil fuels. For example, concrete is the most widely used construction material in the world. Concrete’s main component is cement and CO2 is a side product in cement production. The cement sector alone is responsible for 5 percent of the total global CO2 emissions (Chemistry world, 2008). The construction industry faces the enormous challenge of reducing the negative impact of construction on the world’s health and natural environment in terms of pollution and depletion of natural resources.
The construction industry is the sector that deals with planning, construction, and management of the built environment. This includes buildings and stations, but also infrastructures such as roads, railways, airports, bridges, tunnels and drainage systems (the civilengg, 2014). So far the implementation of sustainable construction projects seems to have focused predominantly on buildings, with less attention on infrastructure, whilst infrastructures are certainly not negligible in the transition towards a more sustainable society (Wong, 2010). Within the process of planning, design, construction and maintenance of new infrastructures, as well as within maintenance and reconstruction of existing infrastructures there should be a major focus on sustainable development. For example, careful choices in relation to materials can make significant changes in terms of environmental impact (Wong, 2010). Therefore, the main focus of this research will be on the sustainable development of infrastructures. In the next section this will be further specified.

1.1.3. Sustainable procurement and EMAT

The addressed issues also create new (economic) opportunities. For example the focus of a country’s policy on sustainability can lead to sustainable governmental purchasing and that way stimulate the creation of sustainable products, innovation and employment. Governmental purchasing is also referred to as public procurement or public tendering and entails the acquisition of goods, services of works from an external source. Public bodies often define processes and rules to promote fair and open competition and to get the best value for the taxpayer’s money (Weele, 2010). For instance, within the EU procurement directives were designed to create an internal market to promote free and fair competition (Europa decentraal, 2014).

An essential step in the transition towards a sustainable society is the way in which a government spends and invests its money. With 18% of the GDP, government procurement accounts for a substantial part of the global economy and it can be a powerful lever in achieving specific social goals (European Parliament, 2014). Sustainable procurement is a powerful instrument for integrating environmental issues into the procurement process and achieving sustainability goals (PIANOo, 2012; UNEP, 2007; Urgenda, 2014).

The United Nations Environment Programme describes sustainable procurement as follows: "A process whereby organizations meet their requirements for goods, services, works and utilities in a way that achieves value for money on a whole of life basis in terms of generating benefits not only to the Organization, but also to society and the economy, whilst minimizing its impact on the environment" (UNEP, 2007).

The Dutch government, together with regional and local authorities, wants to stimulate sustainable products and considers sustainable procurement to be a way of achieving climate goals (PIANOo, 2012; Rijksoverheid, 2013). Sustainable procurement of infrastructural projects contributes to the transition towards a sustainable society. When sustainability becomes a main award criterion for procurement, industry will realize that sustainability has been transformed from nice-to-do to must-do.

In 2012 a new Procurement Act was introduced in the Netherlands; the Public Procurement Act2012 (ARW2012). Since April 1st 2013 contracting authorities have to comply with this new legislation. An important part of this law is the use of a new award criterion for procurement; the Economically Most Advantageous Tender (EMAT). The EMAT criterion enables the contracting authority to take extra criteria, besides price, into account. In this way also qualitative, social and environmental aspects of the tenderer’s submission can be valued during the selection process of the different tender bids (Piano, 2014a). From 2012 on it has therefore become possible to integrate sustainability as a requirement in the procurement process.
Recently, on January 15th 2014, the European Parliament also approved new Public Procurement Directives, which will be binding in all EU Member States. The aim of this new legislation is to ensure that public authorities will purchase best quality and value for money. The new legislation includes the ‘Economically Most Advantageous Tender’ (EMAT) as the standard award criterion. Additionally it includes ‘innovation partnerships’ as a mechanism for stimulating dialogue with bidders and fostering innovation in procurement. “Public procurement will no longer be a question of simply accepting the lowest price. Smart customers will work with smart suppliers to provide better solutions, better tailored to meeting customer needs in more innovative ways,” the British MEP and Rapporteur Malcolm Harbour, Chairman of the EP’s Internal Market and Consumer Protection Committee claimed. Thus the use of EMAT award criterion will become a basis for EU procurements above the EU procurement threshold. One of the purposes of the introduction of the EMAT criterion is to stimulate the use of environmental, innovation and social criteria in public tenders. This master’s thesis gives insights in sustainability in infrastructural projects and more specifically for tunnel construction projects.

1.1.4. Sustainability and sustainable procurement in the tunnel construction industry

It was stated by Duarte (2013) in an issue of the TunnelTalk magazine that the tunneling industry has been slow to embrace current concepts of sustainability for tunnel construction and operation. The article also revealed that a road in a tunnel has, by definition, a higher carbon footprint than a normal road, both during construction and during operation. Lack of measurement criteria and tools is given as one of the reasons why the tunneling industry has been slow to incorporate sustainability into tunnel construction projects.

Desk research on sustainable tunnels supports this notion: only few examples exist of sustainability elements in tunnel construction projects. This, in combination with the lack of recognized sustainability measurement tools in the tunneling world, shows that sustainability has not been a main focus in tunnel construction yet. The lack of examples and tools on sustainability in tunnels makes it difficult to create scoring systems for decision-making on construction of sustainable tunnels.

1.2. Description of the research context

Procurement criteria for sustainability are needed to ensure that sustainable development continues in tunnel construction projects. This thesis is performed in the context of a current tunnel construction project. This project is named “Rotterdamsebaan”, the construction of a road tunnel in The Hague, the Netherlands. In this project sustainability criteria for procurement will be developed. Therefore this project will function as an illustrative example, this can help during the research for identifying problems and providing a network of expertise. However it will not be a case study since the results of this research are aimed at tunnel construction projects in general.

1.2.1. Description Rotterdamsebaan

The “Rotterdamsebaan” is the new link between the Dutch national highway intersection Ypenburg (A4/A13) and the center of The Hague (Binckhorstlaan). The construction of this new roadway will be commissioned by the municipality of The Hague to improve accessibility to the city. Currently there is just one main roadway giving access to the city center of The Hague, the Utrechtsebaan. Other roadways cut through adjacent municipalities. If there is a traffic jam on the “Utrechtsebaan”, most traffic will make use of the other routes that cut through The Hague, Rijswijk and Voorburg-West, which causes nuisance and pollution in these neighborhoods.
The new roadway will put less pressure on the Utrechtsebaan. The location of the new roadway is visualized in figure 1. It starts at the “Ypenburg intersection”, passes under the “Laan van Hoornwijck” and continues through the “Vlietzone”. Just before this zone the roadway goes underground under “Voorburg-West” until it reaches the “Binckhorstlaan” and it exits at the “Mercuriusplein” in the center ring. The Rotterdamsebaan project consists for a large extent of a bored tunnel. The road has a total length of 4 kilometer; the underground part will be 1.86 kilometer. The deepest point of the road will be at 29 meters underground, passing under allotment gardens in Voorburg-West. (Gemeente Den Haag, 2013)

Figure 1 Rotterdamsebaan

This project is currently in the procurement phase. In December 2013, prior to this research, the tenderers have passed the pre-selection phase and several parties have been selected to participate in the dialogue phase. During this research the project was at the start of the competitive dialogue phase. The dialogue will be between the project organization Rotterdamsebaan and the bidders. The selection of the final tenderer is planned in 2015 and the project delivery is planned for 2019.

1.2.2. Sustainability at the Rotterdamsebaan

“Sustainability definitions vary from quality of life, environment, and climate to lifespan. This is also reflected in the generic or even lacking criteria for infrastructural projects.” This was being said by de Alderman of Traffic of the municipality of The Hague Peter Smit. “Regarding the Rotterdamsebaan we want to develop specific criteria for sustainability and underground construction projects.”

This quote from the Alderman of Traffic of The Hague was given in the context of the project the Rotterdamsebaan. The Rotterdamsebaan has been commissioned by the municipality of The Hague and is being executed by the project organization Rotterdamsebaan. This project is currently in the procurement phase and has been procured according to the Public Procurement Act 2012, therefore EMAT will be applied. The first step in incorporating the ambition of the Alderman into the project has been done by defining sustainability as one of the main EMAT award criteria for selection of the different tender bids. This way the project organization wants to stimulate the market to devise innovative and sustainable solutions for the tunnel construction. It has been decided that sustainability is an important criterion in this project. However what The Hague, the Alderman or the project organization means with sustainability within the specific circumstances of the project and the policy goals of the Client is not clear.

There are different views and perspectives towards sustainable tunnels. To achieve sustainable development in this industry, it is important that all stakeholders in the construction supply chain have the same idea of what needs to be developed when discussing sustainable
development. It is also important that within one tunnel construction project all stakeholders have the same idea of what sustainable tunnel development means within that particular project so that they are able to work towards the same goal. Careful selection, ranking and formulation of the sustainability criteria by the client or project organization are important in order to maximally stimulate the market to develop innovative and sustainable tunnel solutions (Dreschler, 2009). If the market is challenged to devise sustainable solutions, then society as a whole can profit from the construction of tunnels in social, economic and environmental ways.

This description of the current situation is based on exploratory discussions with those involved in the Rotterdamsebaan tunnel project. These initial conversations, combined with desk research and expert interviews have resulted in a more detailed description of the current problems surrounding sustainability, tunnels and (EMAT) procurement. A more detailed problem description will be given in the next section.

1.3. Problem statements

There is little expertise, knowledge and experience in defining sustainability aspects for tunnels and integrating sustainability in the procurement phase of tunnel construction projects. This general problem statement will now be specified into specific issues from which this problem exists.

**Problem statement 1: No specific sustainability aspects to secure sustainability in the procurement process of tunnel construction projects exist**

In order to specify and define the sustainability ambitions for the procurement phase of a project a framework with possible sustainability criteria to support the client in their choice would be useful (CROW, 2014). Research into EMAT award criteria in the construction sector confirms that currently only limited literature and systems on EMAT criteria for sustainability in construction projects is available (Dreschler, 2009; Verheijen, 2010; Wong, 2010). The application of EMAT is relatively new; it is only since April 1st 2013 that it has become mandatory to use the EMAT guideline in the Netherlands (CROW, 2012). At European level the law has just been adopted in 2014. The first initiatives for providing award criteria for sustainability by means of an EMAT criteria library is provided by CROW (2014) and DuurzaamGWW (2014). However, these are not specifically applicable to tunnels.

Further research on EMAT award criteria in the construction sector confirms that no specific criteria for tunnel projects exist. Cynthia Sewbalak, head of the legal department Rotterdamsebaan, confirms that no clear, unambiguous EMAT award criteria for sustainability in tunnel projects have yet been developed. Furthermore, there is no experience in developing EMAT award criteria for sustainability within the project organization Rotterdamsebaan.

**Problem statement 2: Sustainability is not clearly defined and specified by clients**

At the end of the procurement process, all tenderers need to be measured and mutually compared, on such matters as sustainability, to arrive at a winning tender. After the selection of the best bid, it must be transparent and explainable why this particular solution is the most sustainable. Therefore a clear definition of a sustainable tunnel within a project and the availability of specific definitions of the different sustainability aspects are important but often lacking. While in order to have a successful procurement the perspective of the project delivery organization (PDO) on sustainable development needs to be clear. An example, as stated earlier, the alderman of transport of The Hague expressed an aspiration to create a sustainable tunnel. Joost Joustra, head of technology at Rotterdamsebaan, commented that this aspiration lacks a precise definition of what sustainability actually means for the Rotterdamsebaan. **This lack of specification of sustainability is something that is seen more often, since sustainability has gradually become a very generic term.**
**Problem statement 3: Sustainability has not yet been embraced by the tunnel industry**

Preliminary literature research confirmed that for tunnel projects no real examples of truly sustainable tunnels exist (Duarte, 2013). No projects could be found that claim to be ‘the most sustainable’. Several tunnel experts, such as Johan Bosch (professor of underground construction) and Paul Janssen (project director Rotterdamsebaan) confirmed that there is little experience on and examples of sustainability in tunnel projects in general. Only some examples of individual sustainability aspects in tunnel construction projects have been identified, such as LED lights in the Vlaketunnel or air filters in the Madrid Calle tunnel. These are the first steps towards the integration of sustainability in tunnel construction projects. However integral and ambitious sustainability approaches in complete tunnel projects have not yet been identified. Also, as mentioned above sustainability is a vague terms and means different things to different people. A lack of insight on the different views on sustainability by stakeholders of a tunnel construction project is problematic. If the PDO and tenderers do not have common ground while talking about sustainability, then there is a chance they will work towards different sustainability goals.

**1.4. Thesis outline**

This chapter has been an introduction to the topic and problem area. In the next chapter the research design will be introduced. The outline this thesis research is shown in figure 2:

![Figure 2 Thesis reading guide](image)

- In Chapter 2 the research design will be introduced
- Chapter 3 describes theoretical context and background information on procurement in general and EMAT procurement specifically.
- In Chapter 4 the process of actual data gathering is described by means of literature and empirical data. This results in an inventory of sustainability aspects.
- Chapter 5 explains the performance of the Q-methodology. This methodology was introduced in chapter 2 in the methodologies part.
- In Chapter 6 the perspectives as a result of the Q-methodology will be presented.
- Chapter 7 presents the results of the aspects; this is the ranking and feedback on aspects.
- Chapter 8 discusses on the results and explains what the managerial implications of this research are.
- Chapter 9 presents the conclusions and short recommendations.
2. Research Design

The identified problem statements show the knowledge gaps and problems surrounding the topic of sustainable tunnel procurement. The problem statement will now be translated into research objectives. Three research objectives will be defined, which form together the main objective.

2.1. Research objectives

**Main objective:** to develop and rank sustainability aspects that can secure sustainability within the procurement process of road tunnel construction projects and to propose an approach to support project delivery organizations in identifying their perspective on a sustainable tunnel and translating this into a selection of relevant sustainability aspects for their specific project.

**Objective 1:** To create a framework of relevant sustainability aspects, which could be used as aspects for securing sustainability in the procurement process of tunnel construction projects.
There is a lack of sustainability aspects, which can be used during the procurement of tunnel construction projects. The creation of these aspects is thus, on the one hand, a scientific contribution, but it is also a practical contribution, if one presupposes that these aspects will be usable for project delivery organizations during the EMAT procurement processes for following road tunnel construction projects.

**Objective 2:** To identify the existing perspectives on sustainable road tunnels.
What determines a sustainable tunnel for different stakeholders in a road tunnel construction project? This research aims at identifying the different perspectives that currently exist on sustainable tunnels and which aspects are most important in determining a sustainable road tunnel construction project. These insights can lead to a better understanding of the sustainability goals on the part of the client, the PDO, the tenderers and other stakeholders in the supply chain of a tunnel construction project. It is expected that these perspectives can also support the client of a sustainable tunnel in recognizing their own perspective and selecting sustainability aspects for their project.

**Objective 3:** To develop an approach that can support clients and PDOs in selecting and ranking sustainability aspects, based on the specific circumstances of the project and their perspective on sustainable road tunnels.
An approach will be developed for the applicability of the framework of aspects (objective 1) and to create a ranking on the aspects. Also this approach will support the client to see besides the current perspectives on sustainable tunnels, what are the perspectives within their specific project. This approach aims to support the client and PDO in in identifying their perspective on a sustainable tunnel and translating this into a selection of relevant sustainability aspects for their specific project.
2.2. Research Questions

Now that the problem description, problem statements and research objectives have been stated, this section will introduce the research questions. To achieve the objectives and close the gaps of knowledge, the following research question needs to be answered during the thesis research:

**Main research question:**
- How to incorporate sustainability into the procurement phase of a road tunnel construction project with regard to sustainability aspects and their selection process?

2.2.1. Research sub questions

In order to answer this main question, the research question has been divided into several sub questions. This helps to make the research comprehensible and structured. However, before the sub questions can be addressed, some preliminary knowledge is needed. An understanding of sustainable procurement and the EMAT award mechanism needs to be developed. Therefore, prior to the sub questions the following questions will be answered in the next chapter.

- What is sustainable procurement?
- How does the EMAT award mechanism work?

After this question has been answered, the more in-depth research can start. This will be done according to the following sub-research questions:

**Inventory of sustainability aspects**

1. What sustainability aspects for tunnel construction projects can be extracted from the literature, expert interviews and reference projects? (Ch. 4)
2. Which set of sustainability aspects can be used as an initial framework? (Ch. 5)

**Current perspectives**

3. What are the current perspectives on these sustainability aspects for road tunnel construction projects? (Ch. 6)

**Framework sustainability aspects**

4. Which final framework of sustainability aspects and which ranking can be used for the procurement phase of road tunnel construction projects? (Ch. 7)

**Approach**

5. Which approach can support a client in selecting and ranking sustainability aspects, based on the specific circumstances of the project and their perspective on sustainable road tunnels? (Ch. 8)

The next figure (3) shows how the problem statements, the objectives and the research questions are connected to each other and to the final outcome of the research.
Once all the research sub questions have been answered then the answer to the main question will follow automatically. The answer to the main research question will be accompanied by recommendations. This conclusion and the recommendations will be presented in the form of advice. This advice is mainly aimed at clients of road tunnel construction projects. Since this research could be executed in the context of the Rotterdamsebaan, in the end specific recommendations will be provided for this project organization as well.

### 2.3. Relevance of the research

#### 2.3.1. Scientific relevance

As mentioned above, there is currently limited literature on EMAT criteria for sustainability in construction projects in general available (Dreschler, 2009; Verheijen, 2010). Furthermore, no literature has been found on tunnel construction projects and EMAT sustainability criteria specifically. This shows that there is a gap in scientific knowledge on this topic. When the formulated research question has been answered, then this research has contributed to the existing scientific knowledge on sustainability, EMAT procurement and tunnels. Also this research will conclude with recommendations for further research, which can lead to more scientific research and knowledge on this topic.
2.3.2. Practical relevance

The research is commissioned by the project organization of the Rotterdamsebaan. The PDO Rotterdamsebaan has been willing to open up their organization so that this research could be conducted in the context of a real project. The idea behind this scientific linkage to the project is that lessons learnt can be made project independent and therewith accessible for future tunnel construction projects with sustainability goals. This way this organization can contribute to the knowledge development on sustainable tunnel procurement. Future tunnel projects, such as the Rijnlandroute in Leiden, are interested in the outcome of this research and the EMAT criteria used in the Rotterdamsebaan, because they need them for their procurement process as well. Possibly all future tunnel construction projects could make use of the framework of aspects since the COB (Centrum for underground construction in the Netherlands) is interested in the outcome for the development of a general tunnel guidelines with specific focus on sustainability. Since EMAT procurement becomes mandatory on a European level, it might as well be useful for tunnel construction projects in other European countries.

Finally, the Rotterdamsebaan is currently developing EMAT award criteria sustainability for their project and this research could provide insights for this as well.

2.3.3. Societal relevance

The construction industry has contributed enormously to the wealth of our society. However at the same time, this industry is a major contributor to environmental pollution. Since this has been recognized and sustainability has become on the agenda of this industry, clients have the responsibility to research and develop sustainable solutions. This is of importance and relevant for all life on earth. It is likely that sustainable development leads to innovation and entrepreneurship, which will stimulate economic development and will create new social opportunities. Furthermore, in order to devise innovative and truly sustainable solutions, different disciplines need to work together on different scales. Since sustainability is an issue that affects all aspects of life it can also contribute to greater social development.

2.4. Role of client and Project Delivery Organization

Within large infrastructural projects, it is important to make a clear distinction between the client and the Project Delivery Organization (Hertogh, Baker, Staal-Ong and Westerveld, 2008). Regarding road tunnel construction projects, the client is often linked to a governmental party, for example the municipality or the province. In the context of the Rotterdamsebaan the client is the municipality of The Hague. The Project Delivery Organization (PDO) is responsible for planning and execution of the project. In the case of the Rotterdamsebaan this organization is the ‘project organization Rotterdamsebaan’, this PDO is still part of the municipality of The Hague. In a typical large infrastructural projects the following distinction in responsibilities between the client and PDO can be made:
This research mainly focuses on defining sustainability aspects to use in the procurement. However to select these aspects the sustainability objectives need to be clear. In an ideal situation this will be defined by the client while making strategic decisions. This way the sustainability objectives can connect to their overall vision on sustainability of for example a particular municipality. However if sustainability is not specified prior to the handover of the project from the client to the PDO, then the PDO needs to specify the sustainability goals in order to select aspects.

### 2.5. Scope

The geographic scope of the research will initially be the Netherlands. As a starting point a Dutch case has been considered and the Dutch procurement law is considered as the legal framework. However, since the EMAT procurement procedure will also become mandatory in other European countries, the framework might be useful for other countries as well. This step will be outside the scope of this research however it will be mentioned as a recommendation for further research.

Even though the Rotterdamsebaan has been used as the context for this research, the aim of the research is to develop a project independent list of sustainability aspects. This framework of aspects can be used as a starting point of every road tunnel construction project. Consequently for every specific project different aspects can be chosen depending on the project scope, ambitions of the client and project environment.

Before it can be chosen which aspects are suitable as EMAT criterion a general set of sustainability aspects for in the procurement phase need to be developed. In this research an inventory of all possible sustainability aspects will be created and this will be filtered using the Q-methodology to a framework with sustainability aspects applicable in the procurement phase of a road tunnel construction project. Besides this framework, perspectives on sustainable tunnels will be identified. The framework, perspectives and proposed approach are insightful for the client before and at the start of the procurement phase. Later on in the procurement phase, based on the project specific characteristics, it can be chosen which aspects are suitable for the project and which can be incorporated as minimum requirements and which as EMAT aspects. This decision moment and the operationalization of these aspects fall outside of the scope of this research. This step has consciously been left out because this

<table>
<thead>
<tr>
<th>Client</th>
<th>Project Delivery Organization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strategic decision to undertake the project</td>
<td>Detailed consultation of the project</td>
</tr>
<tr>
<td>Defining the outputs required and monitoring if these remain valid</td>
<td>Detailed design</td>
</tr>
<tr>
<td>The detailed justification of the project</td>
<td>Obtaining all the relevant consents</td>
</tr>
<tr>
<td>The economic, strategic and societal gain from the project</td>
<td>Programme management</td>
</tr>
<tr>
<td>Determining method of funding</td>
<td>Defining work packages</td>
</tr>
<tr>
<td>High level strategic consultation</td>
<td>Defining contract structure</td>
</tr>
<tr>
<td>Support to PDO in obtaining consents</td>
<td>Tendering of work packages</td>
</tr>
<tr>
<td>Post project operations and maintenance</td>
<td>Letting and supervision of contracts</td>
</tr>
<tr>
<td>Approval of major changes to project scope, cost or timescales</td>
<td>Stakeholder management</td>
</tr>
<tr>
<td>Post project review</td>
<td>Project completion and handover to operation and maintenance</td>
</tr>
<tr>
<td>Knowledge management overall</td>
<td>Knowledge management of design, construction and completion</td>
</tr>
</tbody>
</table>
limits freethinking and creativity. If the participants would already think about rating systems and legal conditions upfront, then they will limit themselves in choosing aspects. Nevertheless after a clear perspective has been defined and coherent aspects have been selected, then the aspects need to be operationalized.

The demarcation within construction projects is tunnel construction projects and more precisely: roadway tunnels. The distinction between road and train tunnels has been made because there exist major differences between them, regarding the traffic tunnel installations, way of use, and the other functionalities lead to other impacts and possibilities regarding sustainability. Different tunnel construction methods exist such as bored tunnels, immersed tunnels and cut-and-cover tunnels, as shown in Appendix D. The context of the research has been the Rotterdamsebaan, which is a bored tunnel. However the distinction between different tunnel construction types becomes only relevant when the separate aspects will be operationalized to come to a measurement system. Therefore this distinction is beyond the scope of this research.

2.6. Methodologies

In this section a description of all methodologies used in this research will be given. In other words: it describes in which way the research questions will be addressed.

The overall research is an exploratory study, since the information available on this subject is very limited and no complete set of sustainability criteria for road tunnels exist. Therefore the overall objective of the research is to gain insight and understanding in which sustainability aspects are suitable for tunnel construction project and their applicability. This way this information gap on this topic will be narrowed. The research is mainly qualitative; this is a form of empirical research in which predominantly qualitative data is used (Baarda, de Goede & Teunissen, 2001). The main research methods are literature research, qualitative interviews, qualitative case studies and Q-methodology. The Q-methodology is a combination of qualitative and quantitative research.

2.6.1. Methods for creating an inventory of sustainability aspects

The data gathering for the answering of this question has been done in three ways: by means of literature research, scanning reference projects and existing assessment tools and expert interviews. The literature used and the experts chosen to interview have different backgrounds so that a wide inventory of sustainability aspects can be covered. The use of different sources is a good way to ‘triangulate’ the data. This means that the result will not depend on a single input and will therefore be more valid (Yin, 2003). The output of this phase is an inventory (concourse) of all possible sustainability aspects. Details about the literature and interviews can be found in chapter 4.

2.6.2. Methodological considerations for determining a ranking

One part of the objectives of the research is to establish a ranking of the sustainability aspects. To be able to rank the different aspects two research methods seemed suitable: the Analytical Hierarchical Process (AHP) or the Q-methodology. The choice for using the Q-methodology has been made. However the trade-off between the AHP method and the Q-methodology will be explained because this can give insights for other researchers making this trade-off. Furthermore the AHP can be used by clients of tunnel construction projects as well.

Analytical Hierarchical Process

Since 2012 the Dutch tax authorities use a software program based on the Analytical Hierarchical Process (AHP) to determine the weighing between factors. This AHP tool is based
on pairwise comparison method (PIANOo, 2014d). The AHP methodology is useful for situations where teams work on complex problems involving perceptions and judgments and have long term implications (Bushan & Kanwal, 2004). Therefore it can be useful for determining the ranking and weighing between the different criteria and aspects in procurement processes involving EMAT award mechanism. In short it can be used for choice, ranking, prioritization and is especially useful if the criteria are hard to quantify and compare and the people involved have different expertise, terminology and perspectives. Especially in cases where it is difficult to make data quantitative the AHP decision making process is useful because the stakeholders /decision makers can still chose which criterion is more important than another; that is a reason why pairwise comparison can be useful. Regarding sustainability this is valuable because long-term implications and aspects such as flexibility and adaptivity can be incorporated as criteria; environmental, economic and social impacts can all be covered (Kasperscyk and Knickel, 2005). The advantages and disadvantages are summed up below;

**Advantages AHP**
- It gives a clear prioritization and/or ranking
- There is an easy and proven tool available (tax authorities tool) which is specified for procurement
- Useful for sustainability criteria
- Qualitative criteria can be taken into account
- For respondents pairwise comparison is straightforward and convenient (Kasperscyk & Knickel, 2004)
- It does not take a lot of time for the respondents
- The AHP method supports group decision-making by calculating clearly and unambiguously the outcome of the geometric mean of the all-pairwise comparisons (Zahir, 1999).

**Disadvantages AHP**
- It is assumed that a prioritization and direct trade-off between sustainability aspects is possible and needed
- Large number of respondents needed
- A larger amount of aspects reduces the impact of the aspects
- It is very ‘black and white’ and as a consequence detailed, and often important, information can be lost (Kasperscyk & Knickel, 2004)
- Input should be the definite aspects (small amount)
- It forces a choice between two

**Introduction Q-Methodology**
The Q-methodology can be used to study subjectivity and to devise collective perspectives about a certain topic (Exel & Graaf, 2005). The method is a foundation for a systematic study on beliefs, attitudes and opinions. The method has been developed by Stephenson (1902-1989) and by using the method different typologies and perspectives out of different opinions and attitudes can be constructed (Brown, 1993). In this area of research this methodology is suitable because different perspectives on sustainability within tunnel construction projects can be identified. Furthermore the method can also be used to determine how the client and experts rank the aspects for sustainability and find out which aspects are important for every tunnel construction project and which aspects are only important within a certain project scope. The perspectives can help to reveal the background problems and difficulties regarding the composition of EMAT aspects for sustainability.

The method is called Q-methodology because of the factor analysis that is needed to analyze the data, which will be collected. The Q sort technique is the basis of the Q methodology and is followed by a factor analysis (Brown, 1980). The Q factors reduce all individual viewpoints to some factors, which the respondents share. The correlation between personal profiles
indicates similar viewpoints or aspects of subjectivity (Brown, 1993). This way Q-factor analysis provides insights on the similarities and differences in perspective on sustainable tunnel construction projects. An assumption of Q is that subjectivity is communicable and can be analyzed systematically (Exel & Graaf, 2005).

During the Q-sorting process all aspects will be sorted and each statements and position can be used once. It forces the respondent to give a relative weighing (Brown, 1993). The Q-method is not about the amount of participants but about 'the representation of different points of view about the topic of study'. A small amount of respondents (if selected well) does not influence the final results, because the goal is to find typologies and not how often a certain typology occurs (Brown, 1980).

**Advantages Q-methodology** (Ten Klooster, Visser, & Jong, 2008).
- Small sample method (it is not about the amount of respondents but the variety of perspectives)
- Can study subjectivity
- The q-sort requires explicitly that people compare objectives and make trade-offs
- It provides a broader perspective, besides the ranking
- Input can still be a broad list of criteria, adjustments and selection can be made later on in the process (while at AHP the definite list should be used as input)
- Can combine qualitative and quantitative aspects
- It is fun to participate and to see the results for respondents

**Disadvantages Q-method**
- It is a relative ranking which is less clear and direct in relation to the AHP
- It is an extensive method
- Time consuming for respondents and researcher
- Factor analyses phase cost much time and effort of the researcher

**Extra value**
- A nice additional effect for the respondents of the Q-research; by sorting and reflecting on the statements it will encourage them to think deeper about the subject of study. Especially for a complex issue as sustainability this can lead to new insights by making sustainability practical and concrete. Furthermore because of the greater social meaning and need for sustainable development this is valuable. The perspectives might be confronting and/or challenging for the participants.

**2.6.3. Substantiating the choice for the Q-methodology**

Both methods are useful but in a different way. Since it is clear that sustainability is such as difficult and broad topic and there is no consensus about assessment criteria, which can be used to judge sustainability in an unambiguous way, it is very valuable to generate perspectives besides the ranking. The different perspectives of all stakeholders in a tunnel construction project might bring a broader and deeper understanding of the issues. It might also help the client in choosing between all sustainability aspects from the framework. The AHP is a very practical tool, especially the version that is developed for procurement purposes. However in the end the underlying and essential question will remain; what does the client want? How does the client see a sustainable tunnel? What is their perspective/vision? The perspectives that will be provided by the Q-methodology research could support the client in identifying their perspective on a sustainable tunnel. Furthermore it is highly likeable that the outcome will not be one clear ranking. The importance of aspects also depends on the project environment and scope. However the Q-methodology can provide insight in which aspects are considered of importance by all different views and perspectives and which are only considered important in certain perspectives. The biggest disadvantage for Q-methodology seems that it is very time-consuming for the researcher to develop the Q-sample, to carry out
all interviews, to analyses and interpret all data and to derive perspectives. For this research a method will be used to conduct the Q-sort online and carry out the research as efficient as possible.

2.6.4. Q-methodology in this research

Before the Q-methodology will be applied to this particular research, a very short description of the terminology and the different steps in a general Q-methodology research will be defined. The Q-methodology is usually practiced in six stages (Barry, Proops, 1999). Also in this study these steps are taken.

Steps in Q-method
1. Define the concourse: identifying the subject of study and gathering all relevant ideas, attitudes, opinions and beliefs surrounding the subject, in this case sustainable tunnels.
2. Define set of statements (Q-sample): establish a set of statements derived from the concourse. In this case the statements are aspects, and the concourse is the inventory that will be created in chapter 4. From this inventory a selection of ‘aspects’, which can be used in the Q-sort, will be made.
3. Select participants (P-set): select a pool of participants relevant for the research topic; this P-set is not a representative group of the general population. In this case the goal is to arrive at current perspectives on sustainable tunnels. The view from stakeholders from the construction supply chain will be most relevant. Which parties will be invited will be discussed in chapter 5.
4. Q-sort: ranking the statements (here aspects) to importance, this will be the outcome of the sorting of statements. For this research that means that the participants will be asked to rank the aspects according to how important this aspect is according to their opinion. The total set of ranked aspects is called a ‘Q-sort’ from that participant.
5. Statistical analysis: the extraction of typical Qsorts or factors, which can be interpreted in the next step.
6. Interpretation of results and derive perspectives. Normally the outcomes are not closely to one particular individual but represent pure or ideal version of how to see sustainable tunnels (Barry et al, 1999).

The first step, defining the subject of study, has by already been done. Chapter 3 provides some background information on procurement criteria. The definition of the concourse and the Q-sample will be done in chapter 4; in this research the concourse is called the inventory of aspects. The selection of the participants as well as the execution of the Q-sorts is described in chapter 5. Chapter 6 will be about the factor analysis and statistical interpretation; this is where the perspectives will be identified. Chapter 7 will use the Q-methodology results to interpret and adjust the final framework with sustainability aspects.
3. Theoretical Context

This chapter provides background information on procurement, the procurement procedure and the EMAT award mechanism. This information is needed before the qualitative in-depth research can start. The topics that will be covered in this chapter are;

- Procurement in general
- Procurement procedures
- EMAT award mechanism
  - Minimum requirements
  - EMAT wishes
- Sustainability criteria in the EMAT award mechanism
- Competitive dialogue procedure

It will be concluded with the implications and conditions for this research.

3.1. Procurement in general

Weele (2010) defines procurement as “the acquisition of goods, services or works from an outside external source. It is favorable that the goods, services or works are appropriate and that they are procured at the best possible cost to meet the needs of the purchaser in terms of quality and quantity, time, and location.” Mostly procurement processes are designed with the aim to ensure fair and open competition. If the purchaser is a governmental body the procurement is called public procurement. Infrastructures are typical examples of works that will be publicly procured since these technical structures support society and enhance societal living conditions. Furthermore transport infrastructures, such as roads, bridges and tunnels, require large investments, which will be paid by the taxpayers’ money. Therefore it is very important that there will be a focus on best value for money, open and fair procurement.

The general procurement process follows specific steps from the view of the contracting authority. This starts with identifying the need of the authority through the last step of awarding the contract, as shown in figure 4.

![Figure 4 Procurement process](image)

The picture above shows which steps the Client needs to follow in the general procurement process:
1. Determining/ identification of needs
2. Set up procurement process/strategy to gain the product
3. Specification phase
   a. Specification of requirements from Client
   b. Specification of the award method (award-criteria) and calculation.
4. Based on the type of tender,
   a. Completely prescribe,
   b. Or functionally prescribe
5. Selection phase; contractors provide a proposal on how to execute the road infrastructure project.
6. A judging committee awards the contract based on the earlier specified award criteria (Regieraad Bouw, 2009).

3.2. Procurement procedures

As explained in the previous section, the procurement consists of various steps. The first step is that the purchaser sets the requirements and specifications about what it exactly wants to
have. This way the price of the work can be estimated, which is needed to define the procurement strategy. If the price of the specified product or service is above a certain threshold value then the project needs be procured using the European procurement procedure. The European Commission sets new threshold values every two years. The new threshold values valid for 2014 / 2015 are shown in table 2:

### Table 2 threshold values

<table>
<thead>
<tr>
<th></th>
<th>Works</th>
<th>Supplies</th>
<th>Services</th>
</tr>
</thead>
<tbody>
<tr>
<td>Special sectors</td>
<td>€ 5.186.000</td>
<td>€ 414.000</td>
<td>€ 414.000</td>
</tr>
<tr>
<td>Central government</td>
<td>€ 5.186.000</td>
<td>€ 134.000</td>
<td>€ 134.000</td>
</tr>
<tr>
<td>Decentral government</td>
<td>€ 5.186.000</td>
<td>€ 207.000</td>
<td>€ 207.000</td>
</tr>
</tbody>
</table>

(European Union, 2013)

Whether or not the procurement will exceed these threshold values, all public procurements must be carried out ensuring openness and fairness. Regarding the EU procurement there are several procedures that the purchaser can chose to follow. The following EU procurement procedures exist:

- **Open procedure**
- **Restricted procedure**
- **Accelerated restricted procedure**
- **Negotiated procedure**
- **Competitive dialogue**

**Open procurement**

Investments in transport infrastructural projects are mostly larger than the threshold values. Therefore an appropriate procedure according to the EU law must be chosen. The open procedure is rarely used in construction since a high number of tenderers can be expected. Furthermore, these kinds of projects have many technical, legal and financial requirements, which cannot be set in this procedure. The restricted procedure and competitive dialogue are two routes, which are most relevant to the construction industry (Sweett, 2012).

**Restricted procedure**

This is a procedure consisting of two phases. In the first stage the contracting authority sets minimum criteria for technical and financial capabilities of the supplier. Evaluating the criteria a minimum of 5 (if at least so many qualify) will be invited to tender for the next phase.

**Accelerated restricted procedure**

This procedure is used when there is limited time. The reasons that the contracting party has for urgency must first be demonstrated in order to get approval to use this procedure.

**Negotiated procedure**

Using this procedure the contracting authority will invite a number of parties to negotiate about the contract. This procedure is now only exceptionally used.

**Competitive dialogue**

This procedure is useful when the contracting authority is not able to objectively define technical needs and objectives and/or their legal or financial objectives. A pre-qualification questionnaire will be completed to select parties to participate in the dialogue. The dialogue will be between the contracting authority and the bidders and they will identify and define the means that will best suit the needs of the purchaser (Sweett, 2012). This dialogue could contain several successive stages and a few bidders can remain which will be invited to tender.
3.3. Specification of criteria

3.3.1. Distinction different kind of criteria

The procurement procedure leads to a choice between different offers/tendering parties based on different kind of criteria (Bruggemen, Chao-Duivis & Koning, 2010). There is a crucial difference between minimum requirements, selection criteria and award criteria. Selection criteria focus on the bidding party (the Scottish government, 2014). These criteria are used to select the parties who meet minimum requirements and which will be invited to tender. The award criteria focus on the bid itself. The contracting authority chooses either to use lowest price as the award criteria or economically most advantageous tender (EMAT). In case of using EMAT, then sub award criteria also called ‘aspects’, need to be developed (Bruggeman et al., 2010).

During the selection phase the selection criteria are used to examine whether the subscribed parties are suitable and capable for the job. These selection criteria must be appropriate, relevant and proportionate to the particular procurement. These criteria are qualitative and should judge on the general suitability and capability of the supplier for the specific assignment. This concerns financial and technical competence and references form past projects. This phase is also called pre-qualification questionnaire (Bruggeman et al., 2010) (the scottish government, 2014).

The award criteria examine the bids themselves. Next section will explain the two possible award criteria.

After the needs are identified, the right procedure could be determined. Depending on the procedure is how the procurement process will be designed. Also the award mechanism has influence on the procurement process design. Therefore the award method needs to be selected.

3.3.2. Award method; lowest price or EMAT

In the traditional way the client exactly described and specified what they wanted from the contractor, for example how the road should look like and how the construction should be executed. Several parties came up with more or less the same design and the party that offered the design for the lowest price would have won the bid and gained the contract. Currently new methods have been designed where not only price, but also quality plays a role. The subscriber with the best price/quality ratio will gain the contract. There are currently two types of tender methods for a European procurement;
- Lowest price
- Best value for money

Best value for money is also called awarding on the basis of the ‘Economically Most Advantageous Tender’ or tender (EMAT). With this method not only price, but also other criteria will play a role in the procurement. This way the bid can also be judged on quality. Quality is a term that can cover many aspects such as functionality, risk, esthetics, sustainability, speed, nuisance prevention, delivery time etcetera. When a number of suppliers submit a proposal about their design and plan and for a certain price there will be selected on the best price/quality ratio. In this research the research scope will be the competitive dialogue procedure and the EMAT award mechanism. A more detailed description about this will be given in the next section.
3.3.3. The EMAT award mechanism

If the client aims for a high quality bid and wants to have certain wishes fulfilled to a great extent, then the client might use the EMAT award procedure to be able to value this extra quality. When using the EMAT procedure requirements need to be set and this will be adopted into the fixed minimum requirements. Besides, additional wishes can be determined. It is important that the client thinks on beforehand how they are going to assess the criteria and how they will measure the extra quality. Every ‘wish’ or quality aspect needs to be developed into an award criterion; this will be called an EMAT sub award criterion. Also the client needs to specify how these scores on the sub award criteria will be mutually compared and in comparison to the price criterion (PIANOo, 2014b).

**Ratio**

The ratio between price and quality is of main importance for EMAT. The biggest problem that could occur is that quality is undervalued and therefore price will again be the dominant criterion. In such a case the EMAT system would have failed and ‘lowest price’ would have been a better criterion.

Each desire or wish from the client should be developed into a valuation criterion; this criterion will then be called an EMAT sub award criterion. All sub criteria together form the EMAT award criterion. The sub criteria can be further specified into sub-sub-criteria; in this research these sub-sub award criteria will be called aspects. The client should indicate how the criteria and aspects will be appreciates in scores. Different weights for different criteria and aspects need to be set.

**Weighing**

The scores for different quality and price aspects are mutually weighted to one final judgment. Also there should be weight within the quality aspects. One aspect can have a greater impact than another on a certain quality sub-criteria. Thus this is besides the price/quality ratio. The weight of the different EMAT sub-criteria and the mutual weight between aspects are important too.

**Distinction requirements & wishes**

There is a difference between requirements and wishes. Requirements have the characteristic of a “knock-out” criterion. If the subscribing party does not fulfill a requirement then the subscription is invalid and this party has no possibility to be awarded. EMAT is a wish/desire and this criterion is not binding. However, it does have consequences for the awarding because if the subscriber fulfills more wishes then it has a bigger chance to be awarded. However the more wishes they tried to fulfill to a high extent, the more costly the bid probably will be. The client should realize that EMAT criteria are wishes and wishes will not always be fulfilled. If it is something they want to adopt for sure then it should be adopted into the minimum requirements. Also the EMAT criterion should be score able and realizable. This is because subscribers should be able to distinguish themselves in relation to the other subscribers on the basis of these EMAT criteria. This distinctive power and variety is needed otherwise the EMAT mechanism would not function well.
3.4. Selection and contracting phase

On the basis of the award criterion EMAT and price a contractor will be selected. Then a contract will be signed between the contracting authority and the contractor. When the contract is awarded, then the execution phase can start.

3.5. Conditions for this research

This chapter has provided a basic understanding of the procurement of a construction project. For road tunnel construction projects with sustainability ambitions, the competitive dialogue procedure and EMAT mechanism are most suitable. There are three types of criteria: selection criteria, minimum requirements and award criteria. The selection criteria are about general suitability and capability of the supplier for the specific assignment and will not be considered within this research.

To arrive at a sustainable tunnel it is important that the ambition of the client will be reflected in both the award criteria and minimum requirements. The in this research to be developed sustainability aspects will be implementable for both. However, it is important to realize the difference between requirements and wishes. Requirements have the characteristic of a “knock-out” criterion. If the subscribing party does not fulfill a requirement then the subscription is invalid and this party has no possibility to be awarded. Thus when an aspect is a condition for a sustainable tunnel or truly important according to the client’s perspective, then this aspect should be adopted as a minimum requirement. The other selected sustainability aspects can then be defined as EMAT award criteria, or “wishes”; these aspects will not be legally binding. Nevertheless, these aspects do have consequences for the awarding process because if the subscriber fulfills more award criteria or some criteria to a larger extent, then it has a bigger chance to be awarded then other tenderers. The client should realize that EMAT criteria are wishes and wishes will not always be fulfilled. If the aspect reflects something that the client certainly wants to adopt, then it should adopt these aspects into the minimum requirements.

This research aims to develop a set of aspects, which can be used both as EMAT award criteria and minimum requirements. The operationalization of these aspects is beyond the scope of this research, however it is importance to realize during the selection of the aspects and approach that subscribers should be able to distinguish themselves in relation to the other subscribers on the basis of these EMAT award criteria. Distinctive power and variation in the solution space for scoring onto these aspects is needed in order to make the EMAT mechanism work. These conditions should be kept in mind while defining the aspects. In Appendix B an entire chapter about operationalization of EMAT aspects can be found. This is not directly relevant for the research but it can provide extra background information.
4. Inventory of sustainability aspects

In this chapter an inventory of sustainability aspects will be created. By doing this the first research sub questions will be answered: *What sustainability aspects for tunnel construction projects can be extracted from the literature, expert interviews and reference projects?*

After the creation of this inventory of aspects, also called concourse in Q-methodology terms, the large inventory of aspects will be filtered. The outcome of this filtering process will be an initial framework of sustainability aspects for road tunnel construction projects. This initial framework forms a ‘Q-sample’ as input for the Q-methodology, which will be executed in the next chapter. By that time the second sub question has been answered: *Which set of sustainability aspects can be used as a Q-sample?*

4.1. Input for inventory

To arrive at an extensive list of possible aspects to judge sustainability in a tunnel construction project, different literature sources, reports and case studies have been investigated and experts were interviewed. To create the inventory a total of fourteen assessment tools, thirteen reference projects; eight expert interviews and four documents from the context of the Rotterdamsebaan have been investigated. In this chapter this process of the creation of the inventory will be described.

Assessment tools
The way in which the sources were studied was not with the purpose to find the precise definitions and details of all aspects, but to create a wide identification of the whole range of sustainability aspects. This scan has been performed as broad as possible, however at the same time, kept in mind that the aspects should be suitable for road tunnel construction projects. For example, building assessment tools have been considered since for buildings many assessment tools on sustainability have already been developed. In the building assessment tool BREEAM-NL New Buildings (2012), for instance, *thermal comfort* is an aspect but this aspect is not relevant for tunnels. Therefore this aspect was not adopted into the inventory. Otherwise, the BREEAM aspect *environmental impact of a site* is on the tunnel construction site at least as relevant as on the building site, therefore this aspect will be included into the inventory. If other assessment tools contain a similar aspect, like *pollution on construction site* then it can be decided to hold on to the first definition, but to note in the inventory that this aspect has been mentioned for the second time in literature. In this way several sustainability assessment tools have been investigated. The most well known tools were building and built environment assessment tools, the ones that have been investigated are;

- BREEAM-NL (2012)
- CASBEE (2013)
- LEED neighborhood (2013)
- GPR Urbanism (2011)
The BREEAM-NL tool originated from the Dutch Green Building Council (2012). Regarding the other tools, an inventory of the criteria of these three tools was made in a master research of a fellow student Stroumpou (2014), this study is not published yet. However in this research the previous mentioned building tools criteria were analyzed. Mentioned criteria were adopted in the inventory if they seemed applicable for road tunnel construction projects. Besides the building tools some infrastructural assessment tools have been studied which can specifically be relevant for road infrastructural projects. The infrastructural assessment tools that have been scanned are:

- Green roads (2014)
- Greenlites - 2012
- Envision - 2012
- BE2ST-in-Highways - 2012
- I-LAST - 2010
- INVEST – 2012

Some aspects have been traced from the website of the tool itself, such as at the Greenroads (2014) rating system website. All other aspects have been identified by use of a paper on comparisons on rating systems of infrastructural projects (Clevenger, Ozbek and Simpson, 2013).

Last, some initial developments towards specific measurements for sustainability applicable for tunnels have been discovered. These tools focus on specific measures such as the consideration of carbon over the entire project life cycle.

- CEEQUAL
- Life cycle
- Cap IT

These tools have already been discussed in the context of tunnel projects in a paper by Duarte (2013). All aspects mentioned here were already selected for potential applicability for road tunnel construction projects; therefore these identified aspects have been directly added to the inventory. This way some new aspects have been identified, and already identified aspects were scored. Which aspects have been added can be found in the Excel file shown in Appendix C.

Documents Rotterdamsebaan

Since this research has been done in the context of the Rotterdamsebaan, there was access to this project documentation. All documents with relation to sustainability have been studied. These documents were the Expert team sustainability (2014), the Environmental Impact Assessment report and the Spatial Plan. The underlying idea of studying these documents was that this wider approach to one project, could lead to new insights and identification of less obvious aspects.

- Framework sustainability by expert team; an initial framework of sustainability criteria for the procurement of the Rotterdamsebaan has been created by expert team sustainability Rotterdamsebaan (2014). This expert team consists of experts in the fields of sustainability, environment, tunnel safety, architecture and geoscience. They have created a framework with nine sustainability aspects for sustainable tunnels and these aspects have been adopted in the inventory. Later on in the discussion on this research the final framework of this master thesis will be compared to the framework initially developed by the expert team sustainability of the Rotterdamsebaan.

- Environmental Assessment Report; This report has been developed by Anteagroup commissioned by the municipality of The Hague for the Rotterdamsebaan a few years prior to the start of the project (The Hague, 2013). In this report traditional environmental issues such as noise, air quality, soil quality and water were studied. A short inventory of sustainability measures were also developed, during an interview with someone who worked on this report all these aspects were identified. The identified aspects have been adopted in the inventory.

- Preliminary Draft; the preliminary draft of the Rotterdamsebaan was developed by Movares (2013). In this preliminary draft the conclusions of pre-research were presented.
In this preresearch also some possible measures and mitigations for sustainability issues have been researched. The conclusions of this research have been discussed during an interview with someone from Movares who was partly responsible for these reports. All identified aspects potentially relevant for sustainable tunnels have been adopted in the concourse.

**Expert literature & interviews**

Besides these documents, experts on underground construction, geology, spatial development and energy have been interviewed. For this phase experts had been selected on their specific field of expertise and without prior knowledge on tunnels. This was done to limitations in the creation of aspects by thinking in terms of feasibility. However these experts were linked to the supply chain of a construction project, to make sure they understand the field of study enough to come up with relevant aspects. The expert interviews went on until saturation of the aspects was reached, this means until the experts started to mention the same aspects as were already mentioned in the inventory. In total eight expert interviews were conducted using the interview format showed in Appendix G.

**Reference projects**

Although no tunnels could be found where on all aspects sustainability measures have been embraced, there are many examples of single sustainability aspects applied in tunnel projects. Reference tunnel projects have been scanned to identify the aspects of sustainability, which have been applied. These have been quick scans in which the websites of the projects have been explored (what sustainability aspects do they promote) and (media) articles have been read. As a starting point, information which was the result of a quick scan on sustainable tunnels by the Ondergronds (2014) has been used. If in these sources sustainability aspects are mentioned that have already been applied in tunnel projects then this can contribute to the credibility, relevance and feasibility of the implementation of specific sustainability aspects. The reference projects that have been scanned are;

1. **Vlaketunnel.** (Istimewa, 2010) (Rijkswaterstaat, 2013)
   *This tunnel is positioned in the South of Holland and goes partly under water, it was built in 1972. During the renovation of the 774 meter tunnel, there was one innovative sustainability aspect: LED lighting. It became the first tunnel in Europe with LED lights. The application of LEDs lead to less energy usage and less maintenance cost.*

2. **Hindheadtunnel.** (Duarte et al, 2013) (Hindhead tunnel, 2014)
   *The Hindhead tunnel covers 1,83 kilometer and is part of the A3 roadway in London. This bored tunnel was opened in 2011. The tunnel replaced a roadway, which initially cut through a nature area. Besides, during the procurement process there was a requirement to achieve a reduction of 50% CO2 emissions. Other innovative aspects were the use of lime/cement stabilization to improve the excavated material and innovative-sprayed concrete lining. The aim of the design was to maximize on-site materials and to reduce the importation of materials.*

3. **M30 Madrid Calle 30 project.** (Cetu, 2010) (CTA, 2013)
   *This tunnel is positioned in the central area of Madrid. The innovative sustainability aspect in the renovation of this tunnel construction project was the application of electrostatic filters to filter fine dust/particles from the air.*

4. **Smart Tunnel.** (Lengaigne, 2010) (Gamuda, 2012)
   *Kuala Lumpur city in Malaysia has a very unique and innovative project. This tunnel has a total length of 9, 7 km, however only 3 km is used as traffic tunnel. The totality of the tunnel length can be used as a storm water buffer. This is a true example of Multifunctionality in a tunnel construction project.*
This railway tunnel connects Rotterdam and Antwerp. The sustainability aspect which is applied in this project is the application of 16,000 solar cells on the tunnel roof. These solar cells spread over a total length of 3km and this leads to a yearly CO2 reduction of 2400 ton.

This Norwegian tunnel is the longest tunnel in the world; it is 24.5 km long. The main sustainability item is the air cleaning system. The tunnel lies very deep under the ground and therefore it has been decided to remove dust by CTA electrostatic precipitators.

7. **Tunnel van de Toekomst** (Tunnelvandetoekomst, 2014)
Unique feature of this Dutch bicycle tunnel located in Oss is the interaction with the user, which is called ‘pleasant pass’. The underlying idea is that this aspect enhances the feeling of safety in the tunnel by the user. This aspect is an example on how experience could be a tunnel aspect. This tunnel could inspire for application of experiencing sustainability aspects while using a tunnel. Also it has a social value.

8. **Fehmarnbelt Tunnel.** (Femern, 2014)
The only aspect that has been identified from this tunnel is the landmark function. This tunnel design focuses on user experience. People should feel safe and if it becomes a landmark there will be a broader support for the tunnel and the construction process will go smoother. Landmark and experience sustainability is also added as an aspect to the inventory.

9. **Gotthard.** (Holcim, 2014)
This large tunnel project in Switzerland focuses on reduction of transport. Transport is one of the sustainability aspects because the rail base logistics enable sustainable transport of the cement to the project site. This leads to reduction of CO2 emissions and reduces road traffic. Also local employment was a focus aspect during this project.

10. **A2 Maastricht** (Projectbureau A2 Maastricht, 2008)
This tunnel project in Maastricht, the Netherlands, incorporates many sustainability aspects. Which aspects have been identified can be found in Appendix C. In short: the surface area of the tunnel will become a green park road, transport movements will be minimized by using local materials, recycling, minimization of construction waste, cooperation with local stakeholders and training of environmental use of machines.

The first time this project has been scanned was on account of an article by the CEEQUAL tool. Some of the sustainability items that were identified: reduce carbon footprint, reduce waste, reuse of materials, land use, biodiversity, water resources, local stakeholders and material use. These aspects have all been highlighted in the inventory. For the creation of the inventory a quick scan was sufficient. However later on the Crossrail project seems the only project discovered so far implementing many sustainability items already, therefore it could have been an interesting case study as well. Unfortunately that did not fit within this research, however there will be reflected on this in the research limitations.

12. **Groene tunnel Bunnik** (Vroege, 2014)
This green tunnel in Bunnik, the Netherlands, integrates several sustainability measures. It is a pilot project for using ‘green concrete’. Fewer resources are needed to create this material. Also energy saving lighting will be applied in the tunnel. Furthermore there will be special attention towards flora and fauna (bee hotel and environmental friendly noise reduction wall) and a holistic approach towards cooperation within the construction project.

13. **Sluiskiltunnel** (DuurzaamBedrijfsleven, 2014) (Mobilis, 2014)
In this bored tunnel project quite some sustainability aspects have been taken into account. All aspects that are adopted in the inventory can be found in appendix C. The most interesting sustainability aspect from this project is the use of Low Energy Asphalt concrete. This saves 30 percent energy and CO2 emissions.
Details about which aspects have been taken into account from the specific projects can be found in Appendix C.

Other
The last report that has been added was the Duurzaam GWW voorbeeldspecificaties (2013). This report seems relevant since it is the most actual report in this sector (sustainable infrastructure projects) in the Netherlands. It covers the most actual tools such as CO2prestatieladder and DuboCalc. The inventory resulted from this report can also be found in the table in Appendix C.

4.2. Selection from inventory to set of aspects

In total an inventory of 102 aspects has been created. A copy of the total inventory is presented in the Appendix C. Between all aspects some overlap exists, these overlapping aspects will be merged and irrelevant aspects will be deleted. This filtering process has led to a set of 35 aspects. The filtering of this extensive list to the first sample will be done based on certain criteria;

- **Occurrence in literature**; the weight of the aspect is based on the amount of times that the aspect has been mentioned in literature; the rule has been defined that every aspect should at least be mentioned three times in literature to be adopted in the concept Q-sample.
- **Variety of sources**; this criteria entails that every aspect should at least be mentioned in different kind of sources; the rule will be that each aspect should at least be mentioned in two kind of sources (either experts, reference projects, elaborated case study or assessment tools)
- **Level of detail**; some aspects are already defined in the form of a solution, and then it is too specific to be an aspect for the Q-sample. It will either be removed or it will be covered by another aspect.
- **Merging low-scoring criteria**; some aspects overlap, as a single aspect they might not score on the criteria mentioned above, however their definitions are so closely related that they could be merged to become a valid aspect that fulfills all criteria mentioned above.

Filtering process

- **If an aspect was only mentioned once** it will not be identified as a main aspect for the Q-sample, example;
  - Smell hinder was only mentioned in one source and is therefore not considered as relevant and deleted from the list
  - Use of clean drinking water was only mentioned once, however this one did not to be deleted but could be covered by a higher level aspect “water saving”
- **If an aspect was already too much specified**, it was not considered suitable for the Q-sample. For example;
  - Waste heat utilization, this aspect was already on the level of a solution. This level of detail does not suit as a sustainability aspect. This aspect could be a mean to reach the overarching aspect “sustainable energy production”
  - Bio engineering techniques, this aspect was too insecure, only one source – can be a solution from the market on the aspect of “environmental conscious selection of materials”
- **If an aspect has only been mentioned once or twice**, but it **was overlapping with many other small aspects**, they could be merged into one broader aspect. Example;
  - The aspects Toxics Reduction, Volatile Organic Compounds, Health are all aspects which were mentioned only once or twice in the sources. However all together they were mentioned ten times, representing different sources, and then they are suitable
for the Q-sample. The new criteria is “healthy project environment by reducing use of toxics”
- The aspects Partnerships with local nature organizations, Cooperation local contractors, Local involvement nature organizations and Social connections environment where all together mentioned eight times and in different sources therefore they could all be merged to one aspect: “local stakeholder involvement”
  - Improving traffic flow was mentioned, (directly or indirectly) in six sources from different origins (expert, case studies and tools). However this aspect is considered as an underlying reason to come to a tunnel development and that this will be improved automatically. Therefore this is not considered as suitable for adoption in the Q-sample although it has been mentioned often enough.
  - One other aspect that was mentioned three times, was only mentioned in one kind of source: the experts. This aspect “total embedded energy of the solution” seems useful as a sustainability aspect for road tunnel construction projects. However since experts have only mentioned it it might be too specific; all stakeholders should understand the Q-sample. Also many aspects in the category of energy have already been defined, thus “total embedded energy of the solution” will be covered by other aspects focusing on energy. It has thus been decided to not specially mention this aspect; however other energy aspects in the framework will cover it.

4.3. Initial framework of aspects

While defining the aspects it is established that the following conditions have been set on the entire framework of aspects:

- All aspects will be considered on their importance for the total road tunnel construction project, thus no distinction will be made between different phases of the project. The impact of an aspect on the entire project life cycle of 100 years is what will be considered.
- All mentioned aspects are aimed ‘beyond regulations’; this especially applies to the ‘traditional environmental aspects’ such as air, water, noise etc.

The process of the selection and definition of sustainability aspects for in the initial framework has been an iterative process. First a broad inventory of all aspects has been made, and then they have been filtered on several criteria. The list of aspects resulted from this first filtering has been shown in Appendix C. After the creation of this first list, two more steps were made until the initial framework was created. First, a target number of aspects for the initial framework will be set and second, appropriate names and definitions of the aspects will be set. Since this initial framework will be input for the Q-methodology, conditions for defining a good Q-sample will be leading for the final filtering step. This will be described in the next section.

4.4. Q-sample

The Q-sample is the set of aspects, which will be used as input for the Q-methodology research. Conditions of defining a proper Q-sample can be useful to look at to design an effective set of sustainability aspects that can function as input for the Q-methodology research. The second research sub question that can now be answered is: Which set of sustainability aspects can be used as a Q-sample?
Number of aspects
Literature shows that opinions about the number of statements for a Q-sample vary. Some researchers argue a minimum deck should at least have 60 statement cards to be statistical stable and reliable (Denzine, 1998). However others argue that a deck can vary between 30 and 100 (McKeown et al., 1999). In the end the amount of statements should accommodate the number of aspects used in this study and reflect the concourse of the topic. Too much will be too time consuming and overwhelming for the participants, From experience that 20 to 35 is ideal, a bigger deck sized participants lose their concentration and are inclined to remain it unfinished (Kralendonk, 2009). While too little will be at the expense of the quality and depth of the research. Therefore a total of 30 to 40 statements (here: aspects) seems best and will therefore be aimed at in this research.

Process of statement definition
After a number of aspects have been identified, the aspect names and definitions can be defined. For the definition of a good Q-sample the following steps can be taken:

- The main aim of a Q-sample is to create a sample that is representative for the wide of existing options on this topic (Exel & Graaf, 2005). This is ensured by first creating the inventory based on a variety of sources and systematically selecting from this inventory.

- The statements need to be edited to arrive at the same level of detail and to be mutual comparable. This has been done in cooperation with a test person from the construction sector that carefully read and tried to compare all initial aspects. If anything was unclear or incomparable since there was overlap or another level of detail, then the definition was adjusted.

- As a last step, the set was tested on clarity of the definitions by a linguistic with no understanding of the topic at all. This person had the ability to independently test the interpretation and understanding of the names and the definitions of the aspects. After this test some minor adjustments were made.

Categorization
The inventoried aspects have been put into categories. These categories are, just like the aspects, emanated from the inventoried sources. These categories have been established to make the inventory visually more appealing. Furthermore in this way it is easier to see if all sustainability themes have been covered and the inventory is more or less complete, then if it were shown in just one list. Also for the output of the Q-methodology it will provide more insight into which groups will score highest on certain categories. This helps with the interpretation of the different perspectives. Each category has about four to seven aspects and altogether seven categories have been established to cover the whole inventory. The themes have been appointed a color. This color has no additional meaning to the theme. The initial framework is presented in table 3.
Table 3 Initial Framework

<table>
<thead>
<tr>
<th>#</th>
<th>Aspect</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Functional flexibility</td>
<td>The ability of the entire tunnel construction to undergo functional adaptations in the future.</td>
</tr>
<tr>
<td>2</td>
<td>Multifunctionality</td>
<td>Practical combination of multiple functions within the tunnel construction project.</td>
</tr>
<tr>
<td>3</td>
<td>Visual and experiential sustainability</td>
<td>The tunnel should communicate a level of sustainability from an aesthetic and experiential perspective and call attention to sustainable solutions.</td>
</tr>
<tr>
<td>4</td>
<td>Climate adaption</td>
<td>Measures and proactive strategies to mitigate and adapt to potential negative consequences of climate change.</td>
</tr>
<tr>
<td>5</td>
<td>Influence on surface area</td>
<td>Allow maximum space for future possibilities of aboveground use.</td>
</tr>
<tr>
<td>6</td>
<td>Design for disassembly</td>
<td>Design in such a way that elements can easily be disassembled for partial or complete re-use, storage or other forms of use at end of lifecycle.</td>
</tr>
<tr>
<td>7</td>
<td>Use of materials and resources</td>
<td>Minimize the amount of materials and resources used.</td>
</tr>
<tr>
<td>8</td>
<td>Origin of materials and resources and environmental impact</td>
<td>Selection of (construction and supporting) materials with consideration for minimal impact on the environment (planet).</td>
</tr>
<tr>
<td>9</td>
<td>Re-use and use of recycled materials</td>
<td>Maximum re-use of components and use of recycled materials and aggregates.</td>
</tr>
<tr>
<td>10</td>
<td>Construction Waste</td>
<td>Minimize (construction) waste and impact thereof on environment.</td>
</tr>
<tr>
<td>11</td>
<td>Energy usage</td>
<td>Minimize energy usage over the total project life cycle.</td>
</tr>
<tr>
<td>12</td>
<td>Energy efficiency</td>
<td>Reduction of the amount of energy required for construction and use of the product and services.</td>
</tr>
<tr>
<td>13</td>
<td>Renewable energy sources</td>
<td>Use of (external) renewable energy sources.</td>
</tr>
<tr>
<td>14</td>
<td>Energy production</td>
<td>Use of the tunnel for the production of renewable energy. (Within project scope)</td>
</tr>
<tr>
<td>15</td>
<td>CO2 emission</td>
<td>Minimize CO2 emissions over entire project. (Particularly in construction phase)</td>
</tr>
<tr>
<td>16</td>
<td>Transport</td>
<td>Limit negative impacts of construction-related transportation.</td>
</tr>
<tr>
<td>17</td>
<td>Fossil fuels</td>
<td>Minimize use of fossil fuels.</td>
</tr>
<tr>
<td>18</td>
<td>Water quality</td>
<td>Prevent pollution and minimize impact of construction on groundwater and surface water quality.</td>
</tr>
<tr>
<td>19</td>
<td>Water usage</td>
<td>Minimize use of (drinking) water during the tunnel project.</td>
</tr>
<tr>
<td>20</td>
<td>Hydrological system</td>
<td>Maintain regular functioning of the (ground) water system and, if necessary, take mitigating measures.</td>
</tr>
<tr>
<td>21</td>
<td>Use of excess soil</td>
<td>High-quality re-use of soil released during construction.</td>
</tr>
<tr>
<td>22</td>
<td>Soil quality</td>
<td>Prevent negative impact on soil quality.</td>
</tr>
<tr>
<td>23</td>
<td>Value of soil</td>
<td>Preserve and protect any cultural value or archaeological heritage present in the soil.</td>
</tr>
<tr>
<td>#</td>
<td>Aspect</td>
<td>Definition</td>
</tr>
<tr>
<td>----</td>
<td>---------------------------------------</td>
<td>-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>24</td>
<td>Biodiversity (Flora and Fauna)</td>
<td>Conservation of biodiversity and ecological connectivity, and compensation of potential negative impact as a result of the tunnel construction.</td>
</tr>
<tr>
<td>25</td>
<td>Noise</td>
<td>Minimize noise pollution in the area surrounding the tunnel.</td>
</tr>
<tr>
<td>26</td>
<td>Air quality</td>
<td>Minimize emissions of air pollutants (e.g. smog, NOx)</td>
</tr>
<tr>
<td>27</td>
<td>Toxic materials</td>
<td>Minimize harmful emissions from toxic materials (VOC’s) and resulting health hazards.</td>
</tr>
<tr>
<td>28</td>
<td>Knowledge exchange</td>
<td>Exchange of information and lessons learned (relating to sustainability practices) with educational and research institutes.</td>
</tr>
<tr>
<td>29</td>
<td>Local stakeholder Involvement</td>
<td>Create public support for the project and activate local expertise among future users, local residents and other stakeholders.</td>
</tr>
<tr>
<td>30</td>
<td>Human rights and fair trade</td>
<td>Comply with international labor standards, respect human rights and enforce an anti-corruption policy. (As per the UN Global Compact)</td>
</tr>
<tr>
<td>31</td>
<td>Social return</td>
<td>Positive contribution to employment in the region and promote employment of people with poor job prospects.</td>
</tr>
<tr>
<td>32</td>
<td>Sustainable leadership</td>
<td>Personal managerial long-term commitment to the project’s sustainability goals, activating internal teams as well as the supply chain as a whole.</td>
</tr>
<tr>
<td>33</td>
<td>Sustainable business operations</td>
<td>A culture of sustainable business practices. (At the construction site as well as within the rest of the company)</td>
</tr>
<tr>
<td>34</td>
<td>Life Cycle Cost</td>
<td>The use of life cycle cost approach to stimulate financial considerations throughout the life cycle of the tunnel</td>
</tr>
<tr>
<td>35</td>
<td>Value optimization</td>
<td>Optimize value of the tunnel throughout the life cycle with consideration for all stakeholders.</td>
</tr>
</tbody>
</table>

### 4.5. Conclusion

The development of this initial framework is a first step towards the development of specific sustainability aspects for road tunnel construction projects. The applicability of these aspects for defining sustainable tunnels will be tested by performing the Q-methodology in the next chapter. This initial framework will be used as the Q-sample. Besides testing the applicability of the aspects, also the completeness of the framework and the definitions can be tested by the participants. Furthermore a ranking within the framework can be created by means of the Q-sorts. In the next chapter the Q-methodology will be performed.
5. Application of the Q-methodology on sustainable tunnels

The Q-methodology was already introduced in chapter 2. However for clarity the steps of the Q-methodology will once be repeated:

1. **Definition of the concourse**: in this research the concourse has been the creation of the inventory.
2. **Definition of the Q-sample and method**: in this case the statements are aspects. These aspects have been selected from the inventory in the previous chapter. This results in a Q-sample. However the way in which this Q-sample will be presented to the participants has not been defined yet. This will be done in section 5.1
3. **Selection of participants (P-set)**: In section 5.2 it will be explained in what way the participants were selected.
4. **Q-sorting**: For this research that means that the participants will be asked to rank the aspects according to how important this aspect is according to their opinion. The total set of ranked aspects is called a ‘Q-sort’ from that participant. The Q-sorting process will extensively described in section 5.3
5. **Statistical analysis**: the extraction of typical Q-sorts or factors, which will be done in chapter 6.
6. **Interpretation of results and derivation of perspectives**: the results of this step will be spread over two chapters: chapter 6 and chapter 7.

5.1. **Definition of the Q-sample and method**

The Q-sample has already been defined in the previous chapter; however in what way it will be implemented was not defined yet. The Q-methodology can be performed in various manners, online or in person.

**Trade-off online versus offline**

This process of Q-sorting can be done in person or online. The major disadvantage of a person-to-person approach is that this process is very time-consuming. The greatest advantage of the person-to-person approach is that the participants are likely to provide extra information to the researcher while sorting the cards. This information can be insightful and helpful for interpretation of the results. On the other hand, this information can, for a large extent, also be provided by asking additional questions in the online Q-sort model. The major advantage of online sorting is that a greater number of participants can be interviewed without making it far more time consuming for the interviewer. Besides, it has been shown in literature that there was no noticeable difference in reliability and validity of using online vs. personal interview type of Q-sorts. Furthermore participants find the online tool more convenient and less messy than the person-to-person approach (Reber, Kaufman & Cropp, 2000). Additionally, participants can perform the Q-sort in their own time planning and (private) location, which provides the participants more freedom and privacy during the Q-sort. Based on the outcomes of this investigation and based on a short interview with two researchers who used the online method before, it has been decided to use the online sorting method for this research.

**Choice of Q-sort method**

Now the decision for use of the online method has been made, there is one more decision to make. Several online tools are available and it should be decided which one suits this research best. Since the online Q-sorting is becoming more popular, multiple online Q-sorting techniques have been developed. An overview of the different tools is provided in table 4. To choose which online model would work best this overview was created to make trade-offs between the possible methodologies. This trade-off is shown in the text since this might be insightful for other researchers who are about to make the same considerations. However the advantages and disadvantages described are very subjective and personal.
<table>
<thead>
<tr>
<th>Method</th>
<th>Developer</th>
<th>Link</th>
<th>Advantage</th>
<th>Disadvantage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q-sorter</td>
<td>Stephan Dekker (VU)</td>
<td><a href="http://www.psy.vu.nl/nl/onderzoek/onderzoeksfaciliteiten/technische-r-and-d/q-sorter/index.asp">http://www.psy.vu.nl/nl/onderzoek/onderzoeksfaciliteiten/technische-r-and-d/q-sorter/index.asp</a></td>
<td>- Dutch developer (easier to contact if something is not clear)</td>
<td>- Looks old-fashioned and therefore not user-friendly</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- looks clear</td>
<td>- not user-friendly</td>
</tr>
<tr>
<td>FlashQ</td>
<td>Christian Hackert – Modified by Rick Hoodenpyle</td>
<td><a href="http://www.hackert.biz/flashq/home/">http://www.hackert.biz/flashq/home/</a> Flash Q - IE 7-8 Christian Hackert - Modified by Rick Hoodenpyle</td>
<td>- free</td>
<td>- a bit outdated, visually not appealing</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- elaborated</td>
<td>- no data analysis</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- requires flash in browser</td>
</tr>
<tr>
<td>WebQ</td>
<td>Rick Watson</td>
<td><a href="http://schmolck.userweb.mwn.de/qmethod/webq/">http://schmolck.userweb.mwn.de/qmethod/webq/</a></td>
<td>- free</td>
<td>- limited space for statement definition</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- no registration</td>
<td>- Looks very old-fashioned (unappealing for users)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- No restricted number of statements</td>
<td>- Based on JavaScript</td>
</tr>
</tbody>
</table>

There are many Q-sorting techniques. To make a choice for the best method several methods have been tried out. However in the end they were all not suitable for this research. Either the text box available for definitions was too small or it was too costly or it would not work on every computer (because of flash requirements). Therefore it has been decided not to use any of the existing tools but to develop an Excel model particular suitable for this research and this Q-sample. Also, since this research has time constraints and all participants would get limited time to perform the research it was considered as important that it would all work perfect and that they interface needed to be appealing and user-friendly for the participants.

**Model development and testing**

After the consideration of the existing Q-methodology techniques, it has been decided to create a Q-questionnaire model in Excel. As a starting point for the development of the model, an existing Excel file with basic characteristics could be used. However this model was not directly usable for this particular research. Many adjustments were made. The different defined steps to carry out the Q-methodology using the Excel model will be described in the 5.3. Now some more information on the model development will be given.
The model development has been an iterative process. The first step was to develop the model in such a way it seemed suitable through the eyes of the researcher itself. This means it was ensured that the steps to be taken would be clear and logically follow after each other. It was ensured that the layout would be clear and visual signs would help to point out what is expected by the participants in each step. Then it was ensured that all couplings between the different tabs in Excel functioned well. When it seemed suitable to carry out the Q-sort, the model was sent to a test person with no experience in these kinds of projects and research. This test was aimed at testing the user-friendliness of the model. After this first step, some bugs were discovered and recommendations for improvement were made and applied by the researcher. Then the model was sent to someone with a background in linguistics, this person was asked just to look at the accompanied text in the model and the instructions. This has led to textual improvements. Furthermore it was then decided by the researcher to add examples including links, for extra explanation on the unusual aspects. This can be seen in Appendix E Tab 2.

The follow-up step was to send the Q-model to someone who did understand the field, but was older than the average age of the final participants, to test the user-friendliness of the Excel model. This person indicated that everything was clear and that it operated smoothly. Afterward, the model could be sent to the first participant, this was actually the final test to see if everything was understood. This person was able to execute the total test within half an hour (which was the time-aim) and had no comments on the method, it was straightforward and worked well he said. Finally the model could be sent out to all participants. All of them were told that if they had any questions during the Q-sorting about the method or the use of the model they could call. However this was apparently not needed and all performed Q-sorts were completed in the right way. This confirms the user-friendliness of the model. What could have contributed to this was that a user-guideline was written to accompany the model.

5.2. Definition of the participant group

The definition of the P-set defines the participants of the research. Since the Q-method is a way to look for typologies and qualitative data the number of participants is less important than the range of viewpoints that is represented within the p-set (Watts & Stenner, 2008). The P-set is not a representation from a general population but a representation of people involved and or having a relevant view or attitude towards a tunnel construction project. In this case ‘relevant people’ are all different parties (firms or advisors) along the construction supply chain. A good representation of the supply chain covers for example a PDO, architect, contractor, tunnel engineer, end-user, supplier and all kinds of experts. All participants are represented in the table below. The aim of the p-set was to have at least one person of every party involved, including different experts and advisors on sustainability and underground construction. An overview of the total set of participants is shown in figure 5.
There were two conditions for all participants, they need to have;

- Some experience with underground construction or infrastructural projects, preferable tunnel projects
- Some experience with sustainability in a project

Every participant has got two labels

- Role in the construction supply chain
- Specific expertise

![Participant set diagram](attachment:image.png)

**Figure 5 Participant set**

**Explanation of the number of participants**

There are several rules of thumb that can be used for defining the amount of participants. Usually two to five perspectives can be derived from Q sorts and three to six individuals define a perspective. This implies that the amount of participants would at least need to be between \((2 \times 3 = 6)\) and \((5 \times 6 = 30)\) participants. However it has been said that it is impossible to know who will determine which factor and therefore it is wise to include more than the minimum amount of people. (Webler, Danielson and Tuler, 2009). For this research it was most important that there was at least one stakeholder from every role in the construction supply chain. Besides, different expertise and viewpoints needed to be covered; the minimum was considered 17 and aimed at 24 participants. To make sure enough participants would participate, a total of 40 people was contacted. In the end, 26 of them participated on time.

With this group of participants all different roles in the construction supply chain and a variety of backgrounds and expertises were covered.
<table>
<thead>
<tr>
<th>Category</th>
<th>ID.</th>
<th>Position in the supply chain</th>
<th>Expertise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Government &amp;</td>
<td>a)</td>
<td>Municipality / client</td>
<td>Stakeholder management</td>
</tr>
<tr>
<td>Society</td>
<td>b)</td>
<td>Provincial Agency</td>
<td>Nature &amp; Environment</td>
</tr>
<tr>
<td></td>
<td>c)</td>
<td>Ministry of Infrastructure and the environment</td>
<td>Coordinator road constructions</td>
</tr>
<tr>
<td></td>
<td>d)</td>
<td>Ministry of Transport, Public works and Water</td>
<td>Contract manager Roads and traffic</td>
</tr>
<tr>
<td></td>
<td>e)</td>
<td>End user</td>
<td>Representing interest of local companies</td>
</tr>
<tr>
<td>Managers</td>
<td>f)</td>
<td>Project/contract manager</td>
<td>Complex infrastructural and soil projects</td>
</tr>
<tr>
<td></td>
<td>g)</td>
<td>Cost manager</td>
<td>Financial expert infrastructural projects</td>
</tr>
<tr>
<td></td>
<td>h)</td>
<td>Project developer</td>
<td>Sustainability advisor</td>
</tr>
<tr>
<td></td>
<td>i)</td>
<td>Project implementation manager</td>
<td>Tunneling</td>
</tr>
<tr>
<td>Project designers</td>
<td>j)</td>
<td>Structural engineering</td>
<td>Tunnels engineering</td>
</tr>
<tr>
<td></td>
<td>k)</td>
<td>Spatial planner / CLIENT’s advisor (Environmental Impact Assessment)</td>
<td>Spatial planning</td>
</tr>
<tr>
<td></td>
<td>l)</td>
<td>Architect</td>
<td>Underground architecture</td>
</tr>
<tr>
<td></td>
<td>m)</td>
<td>Tunnel engineering consulting</td>
<td>Tunnel engineering</td>
</tr>
<tr>
<td></td>
<td>n)</td>
<td>Consulting engineer / advisor of the CLIENT (preliminary design and feasibility studies)</td>
<td>Systems Engineering and Asset Management</td>
</tr>
<tr>
<td>client advisors</td>
<td>o)</td>
<td>Advisor tunnel safety</td>
<td>Structural safety</td>
</tr>
<tr>
<td></td>
<td>p)</td>
<td>Advisor sub-surface construction</td>
<td>subsurface construction</td>
</tr>
<tr>
<td></td>
<td>q)</td>
<td>Advisor technical installations</td>
<td>Tunnel safety and installation technology</td>
</tr>
<tr>
<td></td>
<td>r)</td>
<td>Advisor sustainable procurement</td>
<td>Innovation and market</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Ministry of Transport, Public works and Water</td>
</tr>
<tr>
<td>Environmental</td>
<td>s)</td>
<td>Advisor circular economy</td>
<td>Circular economy</td>
</tr>
<tr>
<td>advisors</td>
<td>t)</td>
<td>Advisor health &amp; environment</td>
<td>Geo engineering</td>
</tr>
<tr>
<td></td>
<td>u)</td>
<td>Advisor environment &amp; hydro-geology</td>
<td>Water and soil quality</td>
</tr>
<tr>
<td></td>
<td>v)</td>
<td>Advisor Life Cycle Analysis</td>
<td>Environmental footprints and Life Cycle Analysis</td>
</tr>
<tr>
<td>Tunnel builders</td>
<td>w)</td>
<td>Main contractor</td>
<td>Project director</td>
</tr>
<tr>
<td></td>
<td>x)</td>
<td>Sub-contractor</td>
<td>Electrical and tunnel technical installations</td>
</tr>
<tr>
<td></td>
<td>y)</td>
<td>Local contractor</td>
<td>Project coordination and civil engineering</td>
</tr>
<tr>
<td></td>
<td>z)</td>
<td>Supplier</td>
<td>Logistics and sustainability</td>
</tr>
</tbody>
</table>

In this section the participants have been labeled with letters ranging from a-z. In the next chapter numbers will be used to assign the different participants. The use of both numbers and letters has been done for privacy reasons. This way the description of the specific role and expertise from one participant cannot be linked to their perspective scores and quotes remain anonymous.
5.3. Q-sorting process

The Q-sorting process was explained in detail in the Excel model and accompanied instructions to the participants. However since the model was developed in Dutch, the Q-sorting process will in this report be explained in English. The first step in performing the Q-sorting process was to make a rough sort. The participants were asked to divide the aspects into three groups. Guided by the following question: “How important do you consider the following aspects for a sustainable road tunnel construction?”

The aspects could be either least important, neutral or most important. By performing this rough sorting process the participants were able to get familiar with the aspects by reading all the definitions. The aspects got presorted which also made it easier to go through the next steps. What this step actually looked like in the model is shows in Appendix E.

The next step was to divide the presorted cards from those three piles on to a grid. This grid has a bell shape. The easiest way for the participants is to start with dividing the cards that they find of greatest or least importance. Because the aspects placed on the extremes are the ones they have the strongest opinion about. Therefore one additional step was created to ask them which two aspects they valued most important (+4) and which two as least important (-4). In a sequential step it was asked to substantiate their choices. When they were done sorting the extremes, they could start to sort the rest of the cards over the remaining middle categories. This step is an essential step for the Q-sorting: this is when the participants make trade-offs between the different aspects. This process goes on until all aspects are sorted and the total grid has been filled.

The participants were asked to sort in total 35 aspects according to how important they considered each aspect. For this sorting process a nine point scale was used; corresponding with -4 is least important, 0 neutral and + 4 most important. The number of aspects for each score was divided as follows;

![Figure 6 Rough sort](image)

![Figure 7 Q-questionnaire](image)
A key characteristic of the Q-methodology is that each aspect needs to be placed at one spot, even though the participant considers all aspects important. This relative ranking is essential for the data analysis.

The last step for the participants in complete the Q-sorting process was to answer some questions. The participant was asked if they had missed an aspect or anything else. The qualitative answers to this question as well as the explanation on the extremes could help with the interpretation of the data. The statistical analysis on the output of the Q-sorting will be performed in the next chapter.
6. Results Perspectives

In both this and the next chapter the results of the application of the Q-methodology will be presented. In this chapter the focus lies on the factors as a result of the factor analysis and the interpretation of these factors into perspectives. This way it will become clear how stakeholders from the construction supply chain currently see a sustainable tunnel.

6.1. Deriving four perspectives using factor analysis

To arrive at different perspectives on sustainable tunnels, the finalized Q-sorts were analyzed using factor analysis. A Q-sort is a completed arrangement of the aspects by participants according to the conditions of the research. The completed Q-sorts reflect the aspect valuations of the participant. The literature term Q-sort will now be replaced by questionnaire. To analyze the questionnaires of the participants and to extract ‘ideal sorts’ the PQ-software program (PQmethod, version March 2014, Release 2.35) was used. Peter Schmolck (2014) has developed this method especially for this type of analyses. All the by the participants completed questionnaires were entered into the statistical program. The computer program correlated each questionnaire with those of other participants, and factor-analyzed the questionnaire based on the Centroid method. The centroid method is a way to extract perspectives from the data of the questionnaires. From the aggregate of 26 completed surveys, eight perspectives were defined, called factors in literature, where a perspective is defined as a series of completed surveys with similar weights for each aspect. To ensure that all participants were attributed to the perspective they most aligned with, a manual control had to be completed. The final outcome of the statistical program was a table with ratings from twenty-six participants on all pre-defined aspects of sustainability in tunnels, aggregated into four distinct perspectives. The first result was a table presenting the correlations between all individual participants; this table can be found in Appendix F. The second relevant table is the outcome of the factor analysis displaying eight possible factors. A factor is the same as a mathematical description of a perspective that is shared by a number of participants. In this research the literature term factor will be replaced and the term perspective will be used instead. To arrive at a final set of perspectives each perspective needed to fulfill two conditions, which are:

1. The eigenvalues of the factor scores need to be above 1
2. At least two questionnaires should attribute (load) significantly on this factor

All eight perspectives complied with these requirements. However, it is of little value to create eight perspectives. A common amount of perspectives for a Q-methodology is two, three or four. Sometimes a fifth perspective is identified and rarely a sixth. Additional perspectives are valuable only if they lead to additional insights on the topic. Typically, the more perspectives are taken into account; the smaller will be the amount of participants attributing on that factor. In this case five perspectives would lead to many non-loaders. A non-loader is a participant that does not attribute significantly on any factor.

The PQMethod varimax rotation has been done five times to check the outcomes from different amounts of perspectives (for arriving at two, three, four, five and six perspectives). In the end it was concluded by the researcher that four perspectives would optimal for this research. This amount of perspectives resulted in a minimum amount of non-loaders, an even distribution of participants over the different perspectives and it seemed that clear narratives could be created from this outcome. The final outcome of this analysis is shown in the following table.
A formula of Brown (1980) was used to establish which Q sorts score significantly on a particular perspective. This is done by calculating the standard error that is \(1/\sqrt{n}\), where \(n\) equals 35 in this research. If we multiply the standard error with \(1.96\times 1/\sqrt{n}\) then we know that participants who load at \(\pm 0.331\) are statistically significant at a level of 0.05. Now we know what the factor loading needs to be, it can be derived from the table above which participants are significant on which perspectives. All participants significant on the 0.05 level have an asterisk. Some participants got appointed two asterisks, which entails that they are confounders. The gray box indicates in which group the participant belongs.

- **Confounders** are participants who attribute (load) on two perspectives significantly: these are participants 8, 10, 11, 16, 21 and 25. Confounders are also called people with hybrid views. These participants are appointed to the perspective where they score the highest. This has been decided because placing them within one perspective gives more meaning to the perspectives and is clearer for the participant as well. It would be a pity to lose their opinion by not placing them within one group. However it is kept in mind during interpretation that these participants scored high on other perspectives as well, this can be relevant for interpretation of the different perspectives.

- **Non-loaders:** are participants that did not attribute (load) significantly on any of the perspectives, in this case 3 participants were nonloaders these are participants 6, 9, and 12. These participants will not be considered during the rest of the analysis, since they

### Table 6 Perspective loadings

<table>
<thead>
<tr>
<th>Participants</th>
<th>Pers. 1</th>
<th>Pers. 2</th>
<th>Pers. 3</th>
<th>Pers. 4</th>
<th>Extra information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participant 1</td>
<td>0.1202</td>
<td>-0.4206</td>
<td>0.1773</td>
<td>0.5647*</td>
<td></td>
</tr>
<tr>
<td>Participant 2</td>
<td>0.0971</td>
<td>0.0205</td>
<td>0.6364*</td>
<td>0.2170</td>
<td></td>
</tr>
<tr>
<td>Participant 3</td>
<td>0.7620*</td>
<td>-0.0375</td>
<td>0.0093</td>
<td>-0.0026</td>
<td></td>
</tr>
<tr>
<td>Participant 4</td>
<td>-0.1971</td>
<td>-0.2357</td>
<td>0.4452*</td>
<td>-0.1168</td>
<td></td>
</tr>
<tr>
<td>Participant 5</td>
<td>-0.1773</td>
<td>0.4674*</td>
<td>-0.0789</td>
<td>0.1138</td>
<td></td>
</tr>
<tr>
<td>Participant 6</td>
<td>0.0391</td>
<td>-0.0097</td>
<td>0.1522</td>
<td>0.1189</td>
<td>non-loader</td>
</tr>
<tr>
<td>Participant 7</td>
<td>0.2812</td>
<td>0.1562</td>
<td>0.3774</td>
<td>0.5315*</td>
<td></td>
</tr>
<tr>
<td>Participant 8</td>
<td>0.4609*</td>
<td>0.5926*</td>
<td>0.1677</td>
<td>-0.0281</td>
<td>confounder: 1 and 2</td>
</tr>
<tr>
<td>Participant 9</td>
<td>0.1437</td>
<td>0.1562</td>
<td>-0.0781</td>
<td>0.1679</td>
<td>non-loader</td>
</tr>
<tr>
<td>Participant 10</td>
<td>-0.2096</td>
<td>0.3648*</td>
<td>0.6410*</td>
<td>-0.0235</td>
<td>confounder: 2 and 3</td>
</tr>
<tr>
<td>Participant 11</td>
<td>0.3169*</td>
<td>0.5587*</td>
<td>-0.0129</td>
<td>0.0318</td>
<td>confounder: 1 and 2</td>
</tr>
<tr>
<td>Participant 12</td>
<td>0.2950</td>
<td>0.0595</td>
<td>0.0828</td>
<td>0.0189</td>
<td>non-loader</td>
</tr>
<tr>
<td>Participant 13</td>
<td>0.8044*</td>
<td>0.1602</td>
<td>0.0904</td>
<td>0.2331</td>
<td></td>
</tr>
<tr>
<td>Participant 14</td>
<td>-0.5955*</td>
<td>-0.0787</td>
<td>0.0792</td>
<td>0.2084</td>
<td>negatively significant</td>
</tr>
<tr>
<td>Participant 15</td>
<td>0.5699*</td>
<td>-0.0490</td>
<td>-0.1291</td>
<td>0.1873</td>
<td></td>
</tr>
<tr>
<td>Participant 16</td>
<td>0.3866*</td>
<td>-0.2501</td>
<td>0.4262*</td>
<td>-0.1951</td>
<td>confounder: 1 and 3</td>
</tr>
<tr>
<td>Participant 17</td>
<td>0.1430</td>
<td>0.7078*</td>
<td>0.0796</td>
<td>0.0010</td>
<td></td>
</tr>
<tr>
<td>Participant 18</td>
<td>0.0456*</td>
<td>0.1667</td>
<td>0.6863*</td>
<td>0.2108</td>
<td></td>
</tr>
<tr>
<td>Participant 19</td>
<td>0.0181</td>
<td>0.0961</td>
<td>-0.1552</td>
<td>0.8742*</td>
<td></td>
</tr>
<tr>
<td>Participant 20</td>
<td>-0.1765</td>
<td>0.6712*</td>
<td>-0.0451</td>
<td>0.0604</td>
<td></td>
</tr>
<tr>
<td>Participant 21</td>
<td>0.1348</td>
<td>0.3680*</td>
<td>0.2633</td>
<td>0.5567*</td>
<td>confounder: 2 and 4</td>
</tr>
<tr>
<td>Participant 22</td>
<td>0.4310*</td>
<td>-0.3083</td>
<td>0.2030</td>
<td>0.1925</td>
<td></td>
</tr>
<tr>
<td>Participant 23</td>
<td>-0.0390</td>
<td>-0.0601</td>
<td>0.8076*</td>
<td>-0.1058</td>
<td></td>
</tr>
<tr>
<td>Participant 24</td>
<td>-0.0265</td>
<td>0.0358</td>
<td>0.0775</td>
<td>0.7621*</td>
<td></td>
</tr>
<tr>
<td>Participant 25</td>
<td>0.6710*</td>
<td>-0.0645</td>
<td>-0.2900</td>
<td>0.3520*</td>
<td>confounder 1 and 4</td>
</tr>
<tr>
<td>Participant 26</td>
<td>0.0180</td>
<td>0.7337*</td>
<td>0.1267</td>
<td>0.0460</td>
<td></td>
</tr>
</tbody>
</table>
have truly unique viewpoints. Since their perspective does not come close to a significant score on any of the perspectives, no consistency with others can be found and interpretation would not create any meaning.

– Participant 14 takes an interesting position: this participant loaded significant on perspective 1, but in opposite direction. This is the only participant with an asterisk (significant loading) but no grey box (not appointed to one factor). This negative loading means that this participant has a totally opposite perspective on the aspects than the participants in the perspective 1 group. So although this participant has nothing in common with perspective 1, the participant does have a strong opinion on the same distinguishing aspects.

Of the in total 26 participants, 22 are attributing significantly to one of the four perspectives. Perspective 1 consists of five people, perspective 2 consists out of six people, and perspective 3 has six participants as well and five participants form perspective 4. This is a fair and even spread.

6.2. Current perspectives on sustainable tunnels

The first result of the Q-methodology was a table representing four perspectives with different groups of participants defining that perspective. These perspectives represent a group of participants sharing a perspective on sustainable tunnels. The results of the questionnaires of the participants are used as the base for creating a narrative for each perspective. In this research this interpretation of the perspectives will be done in close relation to the comments provided by the participants on their most important and least important scores in their Q-sorts. In the next sections different perspectives shared by a number of stakeholders from the construction supply chain will be presented. These current existing perspectives are interesting by itself, but might as well help the Client or project delivery organization by defining their own perspective on a sustainable tunnel and by selecting aspects for in the procurement phase of their project. Because of this use, the narratives have been written in such a way that the aspects are the story line of the narrative.

The first definition of the perspectives is based on the factor scores and empirical data provided by the results of the Q-methodology. After the definition of each perspective there has been done some literature research to check if this defined perspective fits within current existing streams of sustainability as a broader societal topic. If this is the case related literature has been mentioned in a last section with literature support.

6.2.1. The Energy Perspective: “Minimize energy-use, reduce carbon emissions and ensure efficiency over the project life cycle.”

The perspectives can be interpreted based on the highest and lowest scores in the perspective. These are the aspects that participants valued as most and least important. In figure 8, which is depicted below, all aspects with a Z-score above +1 or below -1 are displayed. Z-scores are a measure for how far an aspect deviates from the middle of the distribution (Webler et al., 2009). The total of scores on all aspects of this group can be found in Appendix F.
Most important and least important aspects

Figure 8 Perspective 1 preferences

This perspective was formed by five participants, who all had an analytical background; predominantly engineering and economics. From the figure (8) is noticeable that this group of participants values energy most. Energy efficiency, Renewable energy sources, Energy usage and Energy production are all ranked very high. The main rationale shared by participants in this group is: Use energy as efficient as possible, and use renewable energy and minimize energy usage.

Participant responses

On Energy use there were also some negative comments, participant 22 commented; “Energy, is just like raw materials, it is a mean and not an end in itself. What one achieves by using it, the way it has been generated and its effectiveness that is what is most important.” Accordingly, within energy, the main focus lies on Energy efficiency and Renewable energy sources; these also have the highest scores. Participant 13 commented on Energy efficiency and other energy aspects: “Unlike for above-ground solutions, for tunnels there are many opportunities to save energy in the tunnel construction; both during construction, operation and maintenance. There are also opportunities to win back energy during the life cycle of a tunnel.”

Besides energy, the aspect of Life Cycle Cost has been considered very important. “By making trade-offs based on LCC the client is stimulated to think about the efficiency over the life cycle”. This comment from participant 3 shows that LCC is just like energy associated with efficiency. What is remarkable for this group is that it focuses on efficiency and long-term considerations. “LCC is a way to stimulate sustainable materials and reduce energy use or use it efficiently” was another comment made by participant 15. And participant 13 adds to this: “When the entire life cycle of a tunnel with all its costs is included, then these costs are lower than the costs over the entire life cycle of a bridge. With this way of thinking, tunnels will be more often chosen as the solution opposed to aboveground solutions.” It is clear that this group favors the aspect Life Cycle Cost.
Further Air quality, Material and Resource use and CO2 emissions received high rankings. Material use was already mentioned in relation to energy and LCC. For materials is also said by participant 15: “By production and delivery of raw materials with the least possible use of energy, this also contributes to the reduction of the cost price.” Again materials, energy, and LCC are directly linked to each other. Other comments about materials were: “Raw materials and resources are means used to achieve a specific purpose and are in themselves neutral. Effectiveness, the extent to which they can be reused and so determines the importance”, said participant 22.

One participant commented on Air quality: “The emission of (ultra) fine particles and harmful gases pose a serious threat to the environment as demonstrated by recent studies. This attack on our health is not acceptable and deserves a top priority” said by participant 22. Air quality is the only aspect, which was not directly associated with cost and long term. Nevertheless it could be associated with energy since improving air quality has to do with minimizing emissions. This way the connection to CO2 emissions, Fossil fuels and Energy is made.

As can be seen in the next table (7), CO2 emissions are besides a high score, also a distinguishing aspect for this group. A distinguishing aspect is an aspect that scores significantly different within this group than in all other groups.

Table 7 Distinguishing aspects perspective 1

<table>
<thead>
<tr>
<th>No.</th>
<th>Aspects</th>
<th>Perspective 1 Aspects significantly different than overall mean</th>
<th>Perspective 1</th>
<th>Perspective 2</th>
<th>Perspective 3</th>
<th>Perspective 4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Q-SV</td>
<td>Z-SCR</td>
<td>Q-SV</td>
<td>Z-SCR</td>
<td>Q-SV</td>
</tr>
<tr>
<td>12</td>
<td>Energy efficiency</td>
<td>4</td>
<td>1.73*</td>
<td>2</td>
<td>0.79</td>
<td>1</td>
</tr>
<tr>
<td>15</td>
<td>CO2 emission</td>
<td>2</td>
<td>1.06*</td>
<td>1</td>
<td>0.10</td>
<td>0</td>
</tr>
<tr>
<td>17</td>
<td>Fossil fuels</td>
<td>1</td>
<td>0.68</td>
<td>0</td>
<td>-0.06</td>
<td>-3</td>
</tr>
<tr>
<td>24</td>
<td>Biodiversity</td>
<td>1</td>
<td>0.53*</td>
<td>1</td>
<td>-0.56</td>
<td>-2</td>
</tr>
<tr>
<td>31</td>
<td>Multifunctionality</td>
<td>-1</td>
<td>-0.73*</td>
<td>4</td>
<td>2.04</td>
<td>3</td>
</tr>
<tr>
<td>23</td>
<td>Human rights and fair trade</td>
<td>-1</td>
<td>-0.77*</td>
<td>-4</td>
<td>-1.65</td>
<td>3</td>
</tr>
<tr>
<td>1</td>
<td>Value of soil</td>
<td>-3</td>
<td>-1.39</td>
<td>-1</td>
<td>-0.69</td>
<td>-2</td>
</tr>
<tr>
<td></td>
<td>Functional flexibility</td>
<td>-4</td>
<td>-1.64*</td>
<td>3</td>
<td>1.29</td>
<td>4</td>
</tr>
</tbody>
</table>

“Minimizing CO2 emissions per ton partly stems from efficiency, which has an effect on our (company) cost. Plus, we can present ourselves to the reduction of CO2 emissions per ton; this will increase the likelihood that our client is awarded the contract.” This reasoning from participant 15 shows that CO2 emissions are also associated with efficiency and LCC.

Another distinguishing aspect is Fossil fuels, this group scored relatively high on this aspect, compared to all other groups. This can again be explained in the context of efficiency, as well as the effect of the use of Fossil fuels on CO2 emissions and Air quality.

Functional flexibility receives a very low weight (or rating). This is remarkable since all other groups scored this aspect as most important. Participant 3 commented on this “Although it is a nice ambition, flexibility also requires changes in design. These adjustments may lead more spatial and material needs. This makes the tunnel less sustainable, while there is no guarantee that this flexibility in design is ever necessary.” This explains that this group, which looks from an energy and efficiency point of view, considers flexibility as not efficient. Nor in terms of material use, energy or costs, since it is not certain if this flexibility is needed on the long term.
Social return was no distinguishing aspect, but also a very low scoring aspect with a comment in the same direction: “This is a nice extra aspect, but in the end it is most important that a sustainable tunnel will be realized. Moreover on a ‘macro-economic’ level it does not matter if the employment comes from the region or somewhere further away” said so by participant 13.

It appears that this group of participants values aspects, which are measurable and quantifiable such as CO2 emissions and Air quality the most. This approach to sustainability aspects is in contrast with uncertain aspects such as Functional flexibility, Visual sustainability and experience and the Value of the soil. About Visual sustainability and experience has been said by participant 25: “Visibility and perception are superficial and have short time effect. Sustainability is about the production mode and the creation of raw material cycles. The rest is luxury (important, but not for durability).”

**Summary of Energy perspective**
The Energy perspective assesses the sustainability of tunnel designs based on Energy use, Energy efficiency, Long-term design and Life cycle cost. The Energy perspective was shaped by the responses of five participants with an analytical background. Trade-offs between aspects were made with a long-term perspective and materials and energy should be used as efficient as possible. This perspective values aspects, which are measurable and quantifiable, such as CO2 emissions and Air quality. The technical, analytical and economic background of the group might explain their way of looking over the whole life cycle, long term, focusing on cost and quantifiable aspects. Energy is the most important driver, in terms of quantity (total use) and quality (production method -renewable energy and energy efficiency-). To achieve a sustainable tunnel, an efficient approach has been taken towards all aspects within the construction process. Therefore Multifunctionality does not fit within this perspective, since it is questionable if this leads perse to a sustainable tunnel. The same goes for Flexibility or Visuality these are not considered efficient ways to arrive at a sustainable tunnel. For this group a sustainable tunnel is a road tunnel in which there is a central focus on clean energy production, and an efficiency approach is applied to all aspects during the whole project towards achieving a sustainable tunnel. This perspective would take the following sustainability aspects into account during the procurement process:

1. Energy efficiency
2. Renewable energy sources
3. Life Cycle Cost
4. Air quality
5. Energy use
6. Energy production
7. Material and resource use
8. CO2 emissions

**Literature support**
This first perspective has been defined by empirical data resulting from the Q-methodology. After the perspective has been defined literature research has been done to see if there is any support from literature on the existence of this perspective as a trend within sustainable thinking. First of all it is remarkable that the core belief of the participants on energy use is exactly the same as the idea of the Trias Energica: “Energy efficiency, renewables and clean use of fossils” (Lysen, 1996).

But even in a paper on Sustainability and the tunneling industry a definition of a sustainable tunnel, stated by Duarte (2012), connects to the view of the participants defining this perspective. The definition as used in this paper is that a sustainable tunnel is a tunnel that:

- considers the full project life cycle,
- minimizes usage of the amount of embodied carbon (sum of energy inputs (fuels, materials, human resources) that was used to make the product,
- minimize the use of operational carbon (future emissions),
- complies with current initiatives and represents a holistic approach (Duarte et al, 2012).

It is remarkable that most aspects stated in this article are covered in the definition of a sustainable tunnel by the Energy perspective. The main aspects mentioned in the article are: Energy usage over total life cycle of the tunnel, CO2 emissions and holistic approach. Materials are considered as means and calculated as energy inputs for the tunnel. This connects to the idea of perspective 1 that “production and delivery of raw materials with the least possible use of energy”. In this article it has been said that measurement tools of performance are needed, mainly tools to measure CO2 emissions are mentioned. This also aligns with the perspective 1 approach that the most important sustainability aspects are measurable. Employees of the engineering consultant company Mott Mcdonald have written the article. Therefore it is not surprising that this lies in line with the participants with mainly technical (and some economical) backgrounds of perspective 1.

6.2.2. The Resilience perspective: “Optimize functionality and value over the project life cycle.”

This perspective is defined by the responses of six participants. Most participants have a background from a technical university, mostly civil engineering. Looking at the highest scores of this group Life Cycle Cost, Multifunctionality and Value Optimization stand out. Especially Multifunctionality and Value optimization, in combination with Functional flexibility and Influence on surface area are remarkable combinations. This provides a first impression that the core belief of this perspective is optimization of the functionality of the tunnel over the life cycle of the project.

Participant responses
Looking per aspect and combining the aspect scores with comments made by the participants the following becomes clear about this perspective. Value optimization is, according to this group, about maximizing positive effects and creating added value to the project. Participant 8 commented on the highest score for Value optimization the following: “If we enlarge the pie, everybody gets a larger share. Within a tunnel construction project we can create added value for all stakeholders. There are always people that have ideas to improve the construction or the quality of life in the area, if we jointly address these issues, we can create added value for all stakeholders.”

Figure 9 shows all aspect scores above 1 significant variation and below -1 significant variation from the Resilience perspective group.
Most important and least important aspects

![Graph showing aspect scores (Z-SCR)]

**Figure 9 Perspective 2 preferences**

The categories immediately illustrate that the focus of this perspective lies with Business and operations and Project resilience. First the aspects of project resilience will be discussed.

In combination with Value optimization, the core belief of this group seems that a sustainable tunnel should optimize its functionality.

Both Multifunctionality and Functional flexibility are high scores. Participant 26 says about this “Smart combinations of functions creates added value for the project.” This lies in the same line of reasoning as for Value optimization. Participant 17 added to this: “By combining multiple functions, there is better use of a construction than with a single function. This enhances the life span of the tunnel construction.” This line of reasoning shows that the functionality is considered over the total project life cycle. This is in line with the idea of project resilience.

Life Cycle Cost is the aspect with the highest score. **Life Cycle Cost in combination with Value optimization shows that this group thinks in (business) processes and values systems thinking.** Their technical background could explain the focus on optimization and functionality. Participant 26 explained: “A tunnel should last for many years. Systems thinking and optimization over the entire life cycle therefore provides added value to the project.” Participant 17: “Life Cycle Cost is important to investigate the optimum throughout the life of the structure is, for example, how to make additional investments now to later having to commit less maintenance.” This is interlinked with Multifunctionality and Added value; extra value now can create optimal value over the project life cycle.

Another high scoring aspect is “Influence on surface area” again this can be explained from the same perspective: multiple use of the ground. **Creating extra value on the same piece of land, which is the same as optimization of land.** One of the comments on this was: “Besides limiting disruption to the environment and improvement of traffic flow, multiple use of space is often one of the reasons to choose a tunnel. It should be prevented that with an underground project the possibilities on the surface area will be limited. It is important that from the start of a project, attention is paid to multiple use of space as choices at the beginning of a project..."
(alignment, depth, etc.) can affect the possibilities of use of the surface area greatly” as said by participant 11.

The five highest scores are now discussed and placed in perspective. For more insight we now take a look at table 8 with distinguishing aspects.

Table 8 Distinguishing aspects perspective 2

<table>
<thead>
<tr>
<th>No.</th>
<th>Aspects</th>
<th>Perspective 1</th>
<th>Perspective 2</th>
<th>Perspective 3</th>
<th>Perspective 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>34</td>
<td>Life Cycle Cost</td>
<td>Q-SV 3</td>
<td>Z-SCR 1.37</td>
<td>Q-SV 4</td>
<td>Z-SCR 2.21*</td>
</tr>
<tr>
<td>35</td>
<td>Value optimization</td>
<td>-2 -0.99</td>
<td>3 1.86*</td>
<td>2 1.11</td>
<td>-3 -1.52</td>
</tr>
<tr>
<td>6</td>
<td>Design for disassembly</td>
<td>-1 -0.68</td>
<td>2 1.10*</td>
<td>-4 -2.14</td>
<td>-1 -0.60</td>
</tr>
<tr>
<td>27</td>
<td>Toxic materials</td>
<td>1 0.39</td>
<td>-1 -0.62</td>
<td>0 0.08</td>
<td>3 1.42</td>
</tr>
<tr>
<td>26</td>
<td>Air quality</td>
<td>3 1.36</td>
<td>-2 -0.73*</td>
<td>3 1.28</td>
<td>1 0.51</td>
</tr>
<tr>
<td>13</td>
<td>Renewable energy sources</td>
<td>4 1.42</td>
<td>-3 -1.14*</td>
<td>1 0.36</td>
<td>3 1.28</td>
</tr>
<tr>
<td>31</td>
<td>Human rights and fair trade</td>
<td>-1 -0.77</td>
<td>-4 -1.65*</td>
<td>3 1.38</td>
<td>0 0.06</td>
</tr>
</tbody>
</table>

Life Cycle Cost received the highest score in comparison to the other groups. In addition to the comment of participant 17 about the investigation of the optimum over the project life cycle, other explanations from the group are: “With a life cycle cost approach the most cost effective solutions can be chosen, which is often a benefit in terms of reduced material usage and availability of the tunnel.” Said by participant 11 and participant 8 added to this: “Sustainability is often seen as increasing costs, but if we look at the life of a work does not have to be like this. Change takes time, but thinking in life cycle analysis is a good step.”

An explanation for the high score on Design for disassembly has been given by participant 20: “In fact, the technical translation of functional flexibility is design for disassembly.”

Other distinguishing aspects are the low scores. Human rights and fair trade score notably low. Participant 26 explained that this was not seen as an aspect specifically for sustainability. Because of the low score on social aspects it can be derived that this group does not consider social aspect as essential for sustainability. They define sustainability with aspects focusing on profit (or Business and operation) aspects in combination with Project resilience. The low score for Social return supports this notion. About this aspect participant 20 says: “Social return is a side-issue. The idea for a sustainable tunnel is to construct as efficient as possible and regional employment only makes the project more expensive.”

Renewable energy sources have a distinguishing low score as well. This is again explained in the light of optimization. Participant 20: “Requiring renewable energy often leads to sub-optimization.” A comment of the low score for energy production by participant 5: “Effective combining primary functions of a tunnel with energy recovery is unlikely; there is a high risk of solutions with dramatically poor efficiency. Optimizing a tunnel as a tunnel and optimize energy extraction within energy production is much more effective!” Although this aspect seems about function combinations, something that this group values, this function combination does not seem to support the view on optimization and project resilience. From this it seems plausible to say that this group highly appreciates optimization. And if functions
can be combined, that is great but the functions should be effective and an optimum combination should be found.

There was one participant with a lower score on Functional flexibility than all other participants. Participant 11 commented: “The problem with future changes is that you do not know what is needed in the future. This means that you must take into account many scenarios with high investments, while you are not even sure if it is going to happen.” The interesting thing about this comment is that it is partly in the light of the optimization view, but it could also be explained in the light of efficiency (group one). That makes sense, because this participant has “hybrid view”, this person was attributed to both the Energy perspective as the Resilience perspective.

Summary of Resilience perspective
The Resilience perspective focuses on processes and values systems thinking. The shared belief of holders of this perspective is that a sustainable tunnel should be optimized for its functionality. According to this perspective, Value optimization is about maximizing positive effects and creating added value to the project with an emphasis on process and LCC thinking. The perspective, defined by six participants with a predominant (civil) engineering background, considers optimization problems as interesting challenges. For example, these participants see Multifunctionality as a technical optimization of smart solutions. This group would define a sustainable tunnel as a tunnel that has maximum functionality and value. This perspective would take the following sustainability aspects into account during the procurement process:
1. Life cycle cost
2. Multifunctionality
3. Value optimization
4. Influence on surface area
5. Functional flexibility
6. Design for disassembly

Support by literature
An article by Fiksel (2006) titled ‘Sustainability and resilience: toward a systems approach’ supports the connection of the aspects described in this perspective. Looking at the high scores in the table it becomes clear that the categories of Project resilience and Business and operations are dominating in this perspective. Zoomed in on separate aspects it became clear that optimization is standing out and it has been explained as optimization of smart solutions. In the paper it is mentioned that comprehensive system approach is essential for decision-making in sustainability (Fiksel, 2006). This supports the line of reasoning found within the resilience perspective. It the paper this is also mentioned as ‘sustainable engineering’ or ‘engineering resilience’. The paper describes sustainability as a “system problem requiring collaborative solutions”(Fiksel, 2006). This article supports cohesion between certain aspects. Also mathematical models are mentioned as an approach to engineering resilience. However optimization has not been as explicitly mentioned in this perspective. Therefore the empirical findings of this perspective can only partly be supported by existing literature.
6.2.3. The Social Perspective: “Consider local stakeholders and the direct project environment.”

Six participants defined this perspective. Looking at the chart in figure 10, it is remarkable that this group has ranked Local stakeholder involvement and Human rights and fair trade highly. These social aspects have not received high scores by the other groups. Other outstanding aspects are Functional flexibility and Multifunctionality. A first interpretation of this perspective would be that local stakeholders (social aspects) and functionality of the project are most important.

**Most important and least important aspects**

![Chart showing aspect scores](chart.png)

**Figure 10 Perspective 3 preferences**

**Participant responses**

The high score of Local stakeholder involvement is explained as follows: “It does not suit our society any longer that authority determines what is good for the people. Moreover, the involvement of local stakeholders can lead to the perception that the construction process causes less inconvenience” said participant 23. This is in line with another comment made by participant 4 from this group: “Local turbulence is the biggest retardant of construction projects. Through this early involvement, problems quickly identified or removed.” Clearly this group values the local project environment and how is dealt with people is seen as the key item for sustainability. This connects to what participant 23 said about Human rights and fair trade: “Human rights and fair trade is the basis for a sustainable society,” Also participant 16 added to this: “Equal treatment of people is very important. This is also true for health and safety at work. If that is secured, then I assume that people will focus their energies on the project and not on each other. Moreover, people will be motivated because they are appreciated and are heard. About corruption as a part of fair trade; that is bad for morality and the project and must be fought at all times.”
A high score on *Air quality* can also be explained on the basis of the local project environment, safety and health. This perspective emphasizes that sustainability is mainly a social issue, with a focus on people. A core belief is that if people are involved in the project, if they are appreciated, healthy and safe, then they will contribute to the project and they will automatically value the project, this way the tunnel construction becomes more sustainable.

It is interesting to notice that within the expertise of the participants of this group **project managers** are dominating. In this case not the educational background but their role in the construction supply chain partly explains the perspective.

On the highest score, Functional flexibility, participant 10 commented: “*Within the Netherlands there are an increasing number of underground projects and these projects are in increasingly complex environments. There with multiple use of space, flexibility and adaptivity to new developments becomes increasingly important, especially for tunnels in urban areas.*” Another commented made by participant 2: “It is important for the long term to have the possibility to apply innovative developments to the existing tunnel construction.” Both comments show that it is important to keep an eye on the changing project environment (in terms of policy, innovation and external development). **This means that besides the importance of involving (local) stakeholders, also tracking the changing project environment is considered important for a sustainable tunnel.** One last comment that was made on Functional flexibility by participant 18: “A tunnel is often constructed for 100 years. Since we do not know what the world will look like in the future, it would be nice to be able to use the tunnel for other purposes than traffic.”

There was one participant (16) not scoring high on **Functional flexibility**. This participant commented on this aspect: “To completely change the function of the tunnel brings limitations. There is a chance that many concessions need to be made, because of the available space, the model and the original structure of the tunnel surprises will come.” Although this person did not value **Functional flexibility** highly this participant agrees that it is dependent on external developments and that the project environment should be closely monitored. About **Multifunctionality** is said by the same participant: “You can spend the budget only once. It is always useful and smart, when you can combine two or more goals in one project.” This can also also be interpreted as the project manager’s view.

Like some other groups, this group also finds **Life Cycle Cost** an important aspect, participant 18 explains: “Tunnels are built for at least 100 years. If they are functional flexible they can possibly get another function attributed in the future.”

Most important aspects have now been discussed; therefore a closer look will be taken at the distinguishing aspects, presented in table 9, to further explain the perspective.
Looking at the distinguishing aspects, Local stakeholder involvement and Human rights and fair trade have already been discussed. Other remarkable scores are Value Optimization, Hydrological system and Social return. Regarding Value optimization, this score is relatively high. Participant 10 explained this as follows: “A system approach is often lacking what results in suboptimal choices each time. The tunnel and road are mainly for the environment (surroundings) and not the other way around. Regarding governmental tunnels considerations are primarily made based on the basis of transit traffic. Value optimization for all stakeholders would break this system.” It is interesting to note that even this aspect is explained with a link to the project environment. In this case, and mostly within this perspective, environment is meant in the meaning of surroundings and not per se the planet. People and (local) project surroundings are dominant values in this defined perspective.

Even though it is not the highest score, participants from this group ranked Hydrological system and Social return relatively high, compared to other groups. A high score for the Hydrological system is not surprising, in the context of the (local) project environment, safety and health. Social return is also focused on people and the local orientation of this group.

Many reasons have been given on why Design for disassembly is not important according to the participants sharing this perspective. Participant 2 explains: “This aspect is less interesting for a tunnel. Re-use of the tunnel itself is more obvious.” With this comment the participant refers to Multifunctionality and/or Flexibility as more relevant, which are indeed high scores within this perspective. Participant 16 comments in disfavor for design for disassembly: “This method has been applied in buildings (schools), rarely, if ever, such a structure is dismantled and rebuilt later elsewhere. By that time materials and building methods are outdated.” Whereas in perspective 2 Design for disassembly was seen as a technical translation of functional flexibility. In this group Functional flexibility is ranked as most important and Design for disassembly as least important. This really shows how depended it is from people’s
worldview and perspective how they interpret a certain aspect. It also shows the relation between a set of aspects and the accompanying vision. Single aspects do not make sense, while a set of aspects along with a clear perspective and explanation is much more valuable and insightful.

*Visual sustainability and experience* has been ranked very low by the members of this group. On first sight this does not seem logic since it could be of value for the local stakeholders and project surroundings. However it is explained as follows by participant 23: “*Money can be invested in things that are more favorable to sustainability, furthermore, over time, these kinds of aesthetical and experiential issues will not be noticed by the users anymore.*” It is thus still explained through the ‘local and environment glasses’, but considered unimportant since it is expected that other aspects would lead to a greater impact on sustainability, where it is in the end all about. Another participant added to this: “*It is about the result. If the tunnel scores high in terms of sustainability (innovative solutions) then you will reach the same effect, because the tunnel will serve as a reference project.*” They found this aspect needless.

**Summary of Social perspective**
The participants defining this perspective view a sustainable tunnel as a road tunnel that has been constructed in close cooperation with local stakeholders and with maximum attention for the (changing) project surroundings. Furthermore there should be more functionality to the project than just a road. Six participants defined the perspective, which had different educational backgrounds yet were mostly project managers. The latter could clarify the emphasis on sustainability as a people matter. Their core belief is that if stakeholders are heard and safe, they will value and even contribute to the project. Consequently there will be less hindrance to the project, which makes the tunnel construction project more sustainable. In comparison to the other perspectives this perspective values social aspects very high. But overall it actually balances people, planet and profit aspects in the scoring, which is not surprising since project managers are dominant in this perspective. It is not surprising that this group values *Hydrological system* very high (compared to other groups), this aspect directly influences the local project environment. This perspective would take the following sustainability aspects into account during the procurement process:

1. Functional flexibility
2. Local stakeholder involvement
3. Multifunctionality
4. Human rights and fair trade
5. Air quality
6. Life cycle cost
7. Value optimization

**Literature support**
The combination of social aspects and project environment aspects was already made in the report of the UN World Commission on Environment and Development (1987) report. “*In its broadest sense, sustainable development aims at promoting harmony among human beings and between humanity and nature.*” In this report it was already explained that these aspects should be in balance together with profit. A relation between sustainability and project management is made in an article by Silvius and Schipper (2010). One of the insights described in this paper is: “*Sustainability in projects and project management is about integrating economic, environmental and social aspects in the management and delivery of projects.*” (Silvius and Schipper, 2010) This is a broad view towards sustainability. However the social perspective, mainly defined by project managers, which has been described in this section, does actually balance these three aspects: looking at the highest scores people, planet and profit aspects are in balance. These empirical results, in combination with the described literature, shows that project managers are less likely to go into detailed sustainability aspects than the technical experts in group 1 and group 2 did.
6.2.4. Transition Perspective: “Prevent harmful effects on people and the planet now and on the long-term.”

This perspective is based on the Q sorts of five participants. It is remarkable that none of them has a purely technical background. From the chart it can immediately be seen that this group values Functional flexibility, a project resilience aspect, very high. As participant 7 comments on that: “Sustainability is particularly about whether the project is future-proof and environmental friendly.” One more explanation for the high score on Functional flexibility: “The locations where tunnels are built are often characterized by a lack of space and a multitude of functions. If the tunnel is flexible it can be modified in the near future to new demands from the environment (surroundings).” This immediately reveals the core belief of this group: sustainability aspects are all about the future effect it has on the project environment; on the people and their environment (planet). This seems to be the connecting line between all aspects scoring highest from the following categories: project resilience, energy, health and materials and resource. These will be further explained with reference to the bar chart in figure 11 and the comments made by individual participants.

Most important and least important aspects

![Figure 11 Perspective 4 preferences](image)
Participant responses

Toxic materials have been ranked onto the third place by this group. This aspect is about the effect of the materials on people’s health and on the planet. It has been mentioned that ‘A sustainable project is a project without toxics and chemicals and without environmental harms.’

An interesting combination is the high score for Influence on surface area and Visual sustainability and experience. Influence on surface area is explained by participant 19 as follows: “Multiple land use and planning are needed in urban environments.” Participant 24 stresses the importance of the aspects by a concrete example: “This aspect plays a role within a current land tunnel project where we are searching for appropriate interpretation of the area above the tunnel.”

Besides the focus on future demands from the environment, this aspect does not yet directly emphasize the focus on ‘the effect on people’, however the next aspect explanation certainly does. Visual sustainability and experience is seen as the effect of the project on the view, perception and experience of people. Participant 24 says about this: “Choosing between many aspects, most of them can be summarized in the appearance, look and feel. If many sustainability aspects have been accomplished, then this will result in a sustainable design and appearance.” Participant 21 confirmed the importance of this aspect in the following manner: “This way sustainability becomes physical visible, and is a translation from an abstract term into something concrete and visible.” Participant 21 adds to this: “Not only sustainability in terms of physical and measurable aspects but also aesthetic durability determine the lifespan of an underground space.” It is very interesting that this group values this aspect so high, especially in comparison with the lower scores of other groups.

Participant 21 adds as a general remark: “User-feedback should be used to keep operation and maintenance manageable from the user and also to facilitate changing needs.” This is a unique approach, which could not fit in any of the other groups. However within this group it makes sense to involve end-users and ask them for their (future) needs.

Other high scores within this perspective are Renewable energy sources, Recycling and re-use and Energy use. This is interpreted in the light of re-thinking and re-designing. Participant 1 says: “Let go of the old way, sustainability requires a new approach.” Recycling and reuse, renewable energy sources (gone with the old ones) and an earlier mentioned aspect such as Functional flexibility suits this new approach. The next table (10) with distinguishing aspects will be used to further explain this perspective and this new approach.
Looking at the distinguishing aspects in table 10 it is remarkable that this is the only group that takes Toxic materials as a high score as well as Visual sustainability and experience. Above it has been explained that this is because of the effect it has on people. Human rights is a distinguishing aspect since it scores relatively neutral. Other groups scored this aspect either low or high. Participant 1 explains: “Everything is about people. Sustainability is in the interest of people. Raw materials are of interest to people. Getting along well and dealing in a fair way is the basis of everything.” However it has been assigned a neutral score since it is seen as a normal thing within this perspective. And people are not directly taken into account as an aspect, but all other aspects are translated as their effect on people. Also about the origin of materials is said: “Directly after the interests of ‘fair’ follows the need for materials for the preservation of the human species. Air, water, earth are necessities for survival of humans as a species, and its raw materials. The awareness of this is ‘fair’ after most important for humans.”

The category of Business and Operations has low value within this perspective. One of the remarkable low scores is on Sustainable business operations. Regarding Sustainable leadership and Sustainable business operation, participant 24 comments on this: “Do not hide behind a manager. Enthusiasm for sustainability must come from all stakeholders. Sustainability should not be required, but it should come from within! A manager may encourage but not impose sustainability.” This view connects to participants 1 view that sustainability is about cooperation, together creating a sustainable transition. Participant 21 says about Sustainable business operations: “Within this aspect the concept of sustainability is fast eroded and unusable.” This group agrees that all stakeholders and people from the project surroundings should be involved in the sustainable transition. However they do not think aspects as Sustainable business operations or Sustainable Leadership will contribute to this.

Most notable is the low score on Life cycle cost compared to other groups. Participant 1 comments on this: “Finance and money is finite, just as the linear economy is. When the survival of the human species becomes important as a result of depletion and pollution, a paradigm shift will take place wherein money will become unimportant.” From this can be derived that the focus in on circular economy. The life cycle approach is valued, but not in terms of money and cost. Therefore Life Cycle Cost scores very low. However there is one participant (21) who scored Life Cycle Cost as most important accompanied by the following explanation; “This approach forces to predict the future.” This different view than the rest of the group can be simply explained because this participant has a hybrid-view and is a confounder on this group and group 2. The other group focuses on optimization of value.
Although this participant scored high on Life cycle cost, this participant does not focus on the cost aspect in its explanation of Life Cycle cost. This aspect is interpreted as a way to look into the future, which supports the idea of the need for a new approach.

As an addition Value optimization had also a low score because, according to participant 1, “Although it is actually important, the word "profit" will be brought in relation with money instead of a link to all other values.” To emphasize that cost and money are no indicators of the future it is not ranked as important. This group is clearly not about the profit aspects.

Summary of Transition perspective
This perspective, defined by five participants, considers sustainability aspects with impact on the project surroundings; on the people and their environment (planet). ‘A sustainable project is a project without toxics and chemicals and without environmental harms.’ It also considers the effect on people’s health, sight, perception and experience. Sustainability demands an entirely new approach according to the participants that share this perspective. This group looks into the future and within their future there is no room for profit aspects. According to people from this perspective, a transition is needed; sustainability is about re-thinking and re-designing in many ways. Therefore Functional flexibility is viewed as the most important aspect. ‘Sustainability requires a new approach.’ And this approach is without any harmful future effects on people and planet. This perspective would take the following sustainability aspects into account during the procurement process:

1. Functional flexibility
2. Influence on surface area
3. Toxic materials
4. Renewable energy sources
5. Visual sustainability and experience
6. Recycling and re-use
7. Energy use

Literature support
An article by Tonn (2000) supports the existence of a transition perspective towards sustainability. This article is called “Technology for a sustainable environment: A futures perspective.” The article states that in the future communities are more concerned about sustainability and people want more control over their lives. It describes a possible new world of community-based technology, which supports the focus on renewable energy sources within the perspective defined in this section (Tonn, 2000). The demand for more control can be seen in this perspective by the request for flexibility and minimum influence on surface area. Communities and individuals want to control the environment and do not accept governmental blueprints anymore. Recently there is much development towards ‘transition towns’, according to Samra (2011) this can be the consequence of loss of confidence in the government and development towards a more hands on and positive approach that has led to the birth of transition towns. This positive and proactive approach connects to the statements of participants from this perspective about “rethink, redesign, re-use and recycle.
6.3. Conclusion on perspectives

This chapter started with a quantitative comparison of the questionnaire responses with aspect ratings of all participants (called Q-sorts in literature). The quantitative output of the PQmethod has been interpreted in a qualitative way using participants’ comments. Four perspectives have been identified using the PQmethod. The number of participants was evenly distributed across different groups: each group contained either five or six participants. The views of three participants did not fit into one of four defined perspectives. (Unique perspectives are a phenomenon a project leader will nearly always come across in real projects.) One participant did attribute (load) significantly, but in a negative way onto the Energy perspective. These four participants have been left out of the analysis. All other participants are part of one of four perspectives. The perspectives and their defining aspects are summarized in table 11.

Table 31 Summary aspects per perspective

<table>
<thead>
<tr>
<th>Perspective</th>
<th>Most important aspects</th>
<th>Least important aspects</th>
<th><em>A sustainable road tunnel</em></th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy perspective</td>
<td>- Energy efficiency</td>
<td>- Visual sustainability and experience</td>
<td>&quot;...focuses on energy and efficiency&quot;</td>
</tr>
<tr>
<td></td>
<td>- Renewable energy sources</td>
<td>- Use of excess soil</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Life Cycle Cost</td>
<td>- Value of soil</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Air quality</td>
<td>- Water use</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Energy usage</td>
<td>- Functional flexibility</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Energy production</td>
<td>- Social return</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Material and resource use</td>
<td>- CO2 emission</td>
<td></td>
</tr>
<tr>
<td>Resilience</td>
<td>- Life Cycle Cost</td>
<td>- Energy production</td>
<td>&quot;...is all about optimization of functionality and value</td>
</tr>
<tr>
<td>perspective</td>
<td>- Multifunctionality</td>
<td>- Renewable energy sources</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Value Optimization</td>
<td>- Social return</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Influence on surface area</td>
<td>- Water usage</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Functional Flexibility</td>
<td>- Human rights and fair trade</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Design for disassembly</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Social perspective</td>
<td>- Functional flexibility</td>
<td>- Water use</td>
<td>&quot;...is highly valued by local stakeholders and fits in with the project environment&quot;</td>
</tr>
<tr>
<td></td>
<td>- Local stakeholder involvement</td>
<td>- Recycling and re-use</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Multifunctionality</td>
<td>- Fossil fuels</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Human rights and fair trade</td>
<td>- Sustainable leadership</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Air quality</td>
<td>- Visual sustainability and experience</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Life cycle cost</td>
<td>- Design for disassembly</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Value optimization</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Transition</td>
<td>- Functional flexibility</td>
<td>- Water use</td>
<td>&quot;...cannot have any future harmful effects on people and the planet&quot;</td>
</tr>
<tr>
<td>perspective</td>
<td>- Influence on surface area</td>
<td>- Use of excess soil</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Toxic materials</td>
<td>- Value optimization</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Renewable energy sources</td>
<td>- Sustainable leadership</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Visual sustainability and experience</td>
<td>- Social return</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Recycling and re-use</td>
<td>- Sustainable business operations</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Energy use</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>
A summary of the different perspectives scores on the separate aspects is pictured in the radar chart below. This radar chart provides an overview of the total outcomes of all questionnaires and from this main differences and similarities between perspectives can be derived. For example from this picture it can immediately be derived that the yellow perspective scores highest on all energy aspects. It is clear that this represents the Energy Perspective. What can also be deduced is that all perspectives score quite similar on the soil & water aspects; more qualitative reasoning on this will be provided in the next chapter. A few more remarkable things: the Social Perspective clearly scores highest on social aspects, the Resilience Perspective scores very low on social and health aspects and clearly high on project resilience. The Transition Perspective has remarkable low scores on Business & Operation aspects.

![Figure 12 Overview aspect scores](image-url)
7. Implications of Q-methodology results for final framework

The creation of perspectives was one use of the Q-methodology; another application of the Q-methodology will be the ranking of the entire framework of aspects. Besides this ranking, also consensus and contention aspects could be revealed from the results of the Q-methodology. In this chapter, to begin with the ranking of the aspects will be presented and next, the consensus and distinguishing aspects will be shown and discussed. The third section of this chapter will be about the interpretation of the feedback of the participants provided at the execution of the Q-sorts.

7.1. Ranking/prioritizing of the aspects

A ranking of the aspects could be derived from the output of the factor analysis. This ranking is based on the four perspectives that have been established in the previous chapter. The four perspectives represented four participant groups with representative perspectives on sustainable tunnels. While examining the ranking, it should be kept in mind that this ranking has not been created by an accurate representation of the entire population, but by a selection of stakeholders from the construction supply chain. The participants cover a variety of different backgrounds and expertise’s.

The ranking, which is represented in table 13, is based on all perspective scores with corresponding ranks. The separate aspect scores are the z-scores of the four different perspectives (factors) on the 35 different aspects (initial framework). Z-scores measure how far an aspect lies from the middle of a distribution (Webler et al, 2009). This score can either be positive or negative. A summation has been made from these separate perspective scores on each aspect. The total sum is represented per aspect in the table below.

Table 13 Ranking of aspects

<table>
<thead>
<tr>
<th>No.</th>
<th>Aspect</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>34</td>
<td>Life Cycle Cost</td>
<td>3.83</td>
</tr>
<tr>
<td>2</td>
<td>Multifunctionality</td>
<td>3.44</td>
</tr>
<tr>
<td>12</td>
<td>Energy efficiency</td>
<td>3.26</td>
</tr>
<tr>
<td>1</td>
<td>Functional flexibility</td>
<td>3.21</td>
</tr>
<tr>
<td>11</td>
<td>Energy usage</td>
<td>2.4</td>
</tr>
<tr>
<td>26</td>
<td>Air quality</td>
<td>2.39</td>
</tr>
<tr>
<td>8</td>
<td>Origin of the materials and resources</td>
<td>2.26</td>
</tr>
<tr>
<td>13</td>
<td>Renewable energy sources</td>
<td>1.97</td>
</tr>
<tr>
<td>7</td>
<td>Material and resource usage</td>
<td>1.7</td>
</tr>
<tr>
<td>25</td>
<td>Noise</td>
<td>1.52</td>
</tr>
<tr>
<td>5</td>
<td>Influence on surface area</td>
<td>1.5</td>
</tr>
<tr>
<td>27</td>
<td>Toxic materials</td>
<td>1.24</td>
</tr>
<tr>
<td>10</td>
<td>Construction Waste</td>
<td>1.15</td>
</tr>
<tr>
<td>15</td>
<td>CO2 emission</td>
<td>1.13</td>
</tr>
<tr>
<td>9</td>
<td>Recycling and re-usage</td>
<td>0.94</td>
</tr>
<tr>
<td>4</td>
<td>Climate adaption</td>
<td>0.84</td>
</tr>
<tr>
<td>35</td>
<td>Value optimization</td>
<td>0.69</td>
</tr>
<tr>
<td>20</td>
<td>Hydrological system</td>
<td>-0.12</td>
</tr>
<tr>
<td>14</td>
<td>Energy production</td>
<td>-0.18</td>
</tr>
<tr>
<td>29</td>
<td>Local stakeholder involvement</td>
<td>-0.23</td>
</tr>
</tbody>
</table>
Besides this quantitative ranking, participants also qualitatively reflected on the aspects. After the Q-sorting was completed, participants were asked if they had missed any aspect within the list. The information they have provided by answering this question will be used to check if there are any aspects that need to be added to the framework. These comments will be discussed in section 7.3. To start with, a closer look will be taken to the consensus and contention aspects.

7.2. Consensus and contention aspects

To get an idea of the general view on sustainable tunnels the aspects with most and least agreement between the different groups will now be described. The aspects where there is much agreement about are also called consensus aspects. The ones where there is much disagreement about are called contention aspects.

7.2.1. Consensus aspects

Consensus aspects are those aspects that do not distinguish between any pair of perspectives. That means that overall, all the stakeholders have more or less the same opinion about these aspects. The main consensus aspects are shown in the next table (14).

Table 14 Consensus aspects

<table>
<thead>
<tr>
<th>No.</th>
<th>Aspect</th>
<th>Energy Perspective</th>
<th>Resilience Perspective</th>
<th>Social Perspective</th>
<th>Transition Perspective</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>Transport</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>-1</td>
</tr>
<tr>
<td>19</td>
<td>Water usage</td>
<td>-3</td>
<td>-4</td>
<td>-2</td>
<td>-2</td>
</tr>
<tr>
<td>10</td>
<td>Construction Waste</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>25</td>
<td>Noise</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
</tbody>
</table>
7.2.2. Implications of consensus aspects for final framework

The aspects that are ranked relatively neutral are Construction waste, Transport and Noise. All participants more or less agree on the placing of these aspects. This can be interpreted that these aspects are a neutral base for the final framework. These aspects are not particularly important or highly conflicting. They are also not unimportant, they are merely just not considered decisive for a sustainable tunnel. There is no reason to leave them out or change them.

![Diagram of Consensus Aspects]

Concerning the fourth consensus aspect ‘Water usage’ there is a different interpretation. As is clearly shown in the figure 13 Water usage scores very low by all perspectives. All groups more or less agree about the position of Water usage in the ranking. In contrary to the other consensus aspects, all groups assigned a very low ranking to this aspect (-4, -3 and -2). Therefore it can be concluded that, according to the participants of this research, ‘Water usage’ is unimportant for a sustainable tunnel. It would be interesting to have a qualitative reasoning on this, which will be given in the next section containing the commentary of the participants.

Another approach towards to consensus aspects can be to consider them as a basis for agreement. If it is desirable to reach agreement between groups of stakeholders, these aspects could be used as a starting point for the discussion. On this approach towards consensus aspects, as well as other uses of the aspects in the decision-making process, will be further elaborated in the Chapter 8 Discussion.

7.2.3. Contention aspects

In the following table (15) the contention aspects are listed. These are aspects with noticeable discrepancies between the different groups. While looking at the aspects represented in table 15 it becomes clear that these aspects are indeed the ones that have been extensively described in the previous chapter when identifying the perspectives. Where consensus aspects were barely supportive for the description of the perspectives, the contention aspects have been very meaningful for the interpretation of the different perspectives. Those aspects were the ones that distinguished one group from the other. The contention aspects listed in the table on the next page will be discussed separately.
7.2.4. Implications of contention aspects for final framework

The main contention aspect is Functional flexibility. Although 3 out of 4 groups agreed on a very high score for this aspect, one group valued it on the total opposite of the spectrum. This underpins the idea that it really depends on a perspective taken how it is valued. Different stakeholders in the construction supply chain apparently have very different views on what a sustainable tunnel is and which aspects can be useful for defining a sustainable tunnel. Regarding Functional flexibility, groups 2, 3 and 4 valued this aspect as most important. While group 1 did like the idea, but they found it most important that a sustainable tunnel will be achieved in an efficient way. And since Functional flexibility can be very inefficient because of the accompanied uncertainty, they valued this aspect as unimportant. Since the participants differ greatly on their judgment on this aspect it is for certain an interesting aspect to keep in the final framework.

Value optimization was also broadly discussed in the perspectives chapter. From table 15 it can be understood that half of the groups ranked this aspect positively (+2, +3), while the other two groups provided it with the complete opposite ranking (-2, -3). Group 4 considered value optimization as a financial aspect and therefore provided it with a low ranking, whereas group 2 looked upon it as value creation for all stakeholders and enlarging the total project benefits. Since there are some groups which found this aspect very important it is certainly taken into account for the final list of aspects.

The third contention statement is Visual sustainability and experience this aspect received one very high score by group 4, two very low scores by group 1 and 3 and one neutral score by group 2. Group 4, which scored this aspect highest, is the group with a main focus of tunnel’s indirect effects on people and the planet. Interesting is that group 3 values overall local stakeholders and the project surroundings, but ranked this aspect as least important (-4). These differences in interpretation of this aspect are very interesting. Apparently for the indirect future effects of the tunnel on the people and project surrounding this aspect is considered very important, however for direct effect on the (local) project environment it is not. This cannot fully be explained by short comments. This aspect requires further discussion. But it shows that it is an interesting aspect, which will certainly be part of the final list; however it might need more clarification. A closer look to the definition will be taken later on in this chapter.

<table>
<thead>
<tr>
<th>No.</th>
<th>[Contention aspects]</th>
<th>Questionnaire scores</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Energy Perspective</td>
</tr>
<tr>
<td>1</td>
<td>Functional flexibility</td>
<td>-4</td>
</tr>
<tr>
<td>35</td>
<td>Value optimization</td>
<td>-2</td>
</tr>
<tr>
<td>3</td>
<td>Visual sustainability and experience</td>
<td>-2</td>
</tr>
<tr>
<td>34</td>
<td>Life Cycle Cost</td>
<td>3</td>
</tr>
<tr>
<td>6</td>
<td>Design for disassembly</td>
<td>-1</td>
</tr>
</tbody>
</table>
Another way of looking at the contention aspects can be looking why it is that only one group did not value a certain aspect, such as is the case for Life Cycle Cost. The figure above (14) makes these differences visible. It might be the case that because of different interpretations of the concept or because of the level of specification the whole aspect has been valued differently. For example in this case, only group 4 did consider LCC as unimportant, while at the same time, mentioning the need for a life cycle approach. According to participants of perspective 4 this aspect is too much focused on cost. Since most groups ranked this aspect very high it will included in the final list.

In general Design for disassembly did not receive a high ranking. The one group that valued it as quite important (group 2) was the group, which had the explanation that Design for disassembly, is just a technical translation of Functional flexibility. Therefore it can be considered to remove Design for disassembly from the final framework in order to prevent a redundant or superfluous aspect. Whether or not this aspect will be removed will be discussed in the next section on missing aspects.

The complete table with all aspects and their ranking on the range from consensus to contention is displayed in Appendix F.

### 7.3. Aspects missing from the framework

Besides the contention and consensus aspects, more information has been retrieved from the Q-sorts. During the Q-sorting participants were asked if they had missed an aspect. From all 26 participants, only seven have indicated that they missed an aspect. Regarding the information about missing aspects, feedback from all participants, thus also from the non-loaders and negative loader, has been taken into account. Some aspects seemed to be lacking from the framework, other comments might be about the interpretation of a certain aspect.

- Participant 1 missed everything about the coordination from extraction to reentry.
- Participant 25 missed supply chain cooperation and integration. “The list of aspects is now too much focused on the client and contractor, while the production chain is much bigger than that.”
- Participant 5 missed 3 aspects: Future proof design, future proof implementation, and the quality of the used materials (both in appearance and look-and-feel)
Participant 9 said to be missing: **maintenance free design** “Even though Life Cycle Cost is one of the aspects, I missed Life Cycle Project regarding preventive sustainability aspects such as maintenance free design.”

Participant 12 indicated to miss an aspect on **Economical and efficient material use and referred to a paper** “Economical and efficient use of materials could have more explicit attention.”

Participant 14 missed **local purchasing**

Participant 23 missed **internships**

**Feedback participant 1 and participant 25: supply chain**
Feedback provided by participant 1 and participant 25 are in the same direction. Both noted that an aspect considering the entire supply chain was missing. It has been considered during the definition of the final framework to add an aspect regarding this topic, and it was then decided to take **Sustainable leadership** into account. **Sustainable leadership** has in this context been explained as follows: “Personal managerial long-term commitment to the project’s sustainability goals, activating internal teams as well as the supply chain as a whole.” Although activating the entire supply chain towards sustainability goals has been mentioned within this definition, it might not have been specific enough. Since it has now explicitly been mentioned twice, a new aspect will be added to the framework that will be called: **‘Coordination, collaboration and integration in the Supply Chain’** This new aspect covers both aspects suggested by participant 1 and 25. This name has been chosen because of its use in practice by Moharana (2012). Also the definition for this new aspect will be retrieved from this paper. ‘Create easy access for coordination, collaboration and integration of key business processes from end user through original suppliers providing products, services and information that add value for customers and other stakeholders.’

**Participant 5: future proof**
Participant 5 believes that three aspects are missing. First of all **Future proof design**, this has to do with visuals and how people perceive the tunnel in the future. This is actually linked to the aspect **Visual sustainability and experience**. However, it appears that ‘Visual’ does not seem the right word; it is not broad enough, since it was just interpreted as visibility of the solutions. Therefore it has been decided to change the word Visual into ‘Aesthetic’ the new term becomes: **‘Aesthetic and experiential sustainability’**. This way this aspect has a broader definition and more coverage. The suggested other aspect ‘quality of the materials in the sense of appearance and look-and-feel’ should now fit in with this aspect as well.

**Future proof implementation** is about the integration of the tunnel into the landscape. The first impression is that this aspect is connected to ‘Influence on surface area’. However, after some desk research, it does in fact have a different meaning. Influence on surface area has been defined in the framework as ‘Allowing maximum space for future possibilities of aboveground use’ this means that there should be no limitations for the use of the surface area as consequence of the tunnel construction. While future proof implementation has a broader meaning. For example, a project has been discovered where this aspect has successfully been used in the procurement phase: this project is named ‘Graafseweg (N324)’ in Alverna (Provincie Gelderland, 2013). The aspect used in that case was called ‘landschappelijke inpassing’, a Dutch word, which can be translated as ‘Landscape integration’. However since in that project the solution to this aspect was in that project a deepened construction of the road this solution could have scored on the aspect Influence on surface area as well. Therefore it has been decided to merge these aspects. Since “Landscape integration” has a broader reach this name has been adopted. Since the name has changed, the definition will also be broadened. The new definition will be ‘Allow maximum space for future possibilities of aboveground use and respond to landscape character’. The addition ‘respond to landscape character’ has been derived from the award criteria used in the N324 project.
It is remarkable that participant 5 mentions two aspects with emphasize on ‘future’. Participant 5 is not part of the future perspective, but is part of the Resilience perspective. However the second highest loading of this participant was indeed on the future perspective. It is also true that within the resilience perspective emphasize lays on resilience and flexibility, which also has the meaning of providing flexibility for the future (generations). In this way these two perspectives have interfaces. These kinds of discussions on aspects and on interfaces between perspectives would be very valuable within procurement processes and teams. Further elaboration on this application of the Q-methodology will be given in the next chapter.

Participant 9: Life cycle project
Participant 9 said to be missing an aspect for Life Cycle Project, specifically aiming at preventive sustainability aspects such as maintenance free design. Although it can be assumed that if the use of materials was chosen in a sustainable way these will automatically be materials with less maintenance. However Maintenance free design covers more than materials alone, and furthermore, it is good to have a more specified direction. Desk research showed that this aspect has already been used in the procurement of a road construction project. In the procurement of the project ‘N322 Beneden Leeuwen-Druten’ an aspect named “environmental friendly maintenance” was used (province Gelderland, 2013). The solution for this aspect was “sheep will keep the green at the sides of the road short, wooden fencing prevents stray light to the surroundings and the lights along the roads are ‘bird-friendly’ by making use of - literally - green lights”. This solution however is not applicable for a tunnel at all and it is focused on environmental friendly maintenance, it does show that an aspect in this direction can work and can lead to creative solutions. To conclude: “Maintenance free design” will be added to the final list of aspects. While doing research to the right definition it has been decided to call the final aspect “Operations and maintenance optimization.” This has been decided since maintenance free design is unrealistic for a tunnel construction project. Furthermore this new definition also covers a part of enforcing the overall sustainability ambitions. This new definition has literally been adopted from the Whole Building Design Guide (2013). “Ensure operation and maintenance personnel are part of the project planning and development process, including the establishing of commissioning criteria at the onset of a project.”

It is interesting to see that the aspect of Life cycle project was mentioned. In the section on contention statements Life Cycle Cost was highly scored by all groups, excluding group 4. They did value the life cycle approach; however they did not value the LCC aspect as important. This because of the emphasize on cost. It would be expected that participant 9 would be part of perspective 4 since the line of reasoning on this missing aspects fits within that perspective. Looking back at the participant scores in the previous chapter, participant 9 was a non-loader. However the highest loading was indeed on perspective 4, the Transition perspective. Just like mentioned above, these kinds of links are interesting to discover and this would help to create mutual understanding during a procurement process.

Participant 12: efficient material use
Participant 12 indicated to miss an aspect on Economical and efficient material use. “Economical and efficient use of materials could have more explicit attention” is what the participant literally said. Furthermore this participant referred to a paper about sustainable management of the subsurface. In this paper the frugality principle is mentioned, what is described as: “People in the vicinity of a resource should use the resource to a minimum so that it remains available for others. It holds in particular for water as a flowing resource, where consumption is minimized in the upstream part” (Griffioen et al., 2014). Water use is particularly mentioned within this definition, while, based on the empirical results, this aspect has just been removed from the final list of aspects. Though, the intention of the principle is more focused on that resources are used to a minimum and in a sustainable way, and water can be seen as an example of such a resource. Participant 12 added to this “The tunnel is accompanied by a large amount of resources and the sustainable use of it can be the biggest
step forward in terms of sustainable tunnels.” Therefore it has been decided to redefine the current aspect *Use of materials and resources* to a new name that is more explicit towards sustainable usage. The new name of this aspect will become: “Frugal and efficient use of materials and resources.” The definition of the aspect will remain the same.

Participant 14: local purchasing
Participant 14 have named local purchasing as a missing aspect. Surely this aspect is important, however it is not seen as a single item but it has been integrated into one aspect, namely: Involvement of the local stakeholders. This choice has been made in chapter 4 when the inventory of aspects was merged into a list of 35 aspects. The definition of this aspect is “To create public support for the project and activate local expertise among future users, local residents and other stakeholders.” The definition of the aspect will remain the same, mainly since with the addition of Coordination, collaboration and integration in the Supply Chain there is already more emphasize on the purchasing process.

Participant 23: internships
Lastly, participant 23 mentioned Internships as a missing aspect. In chapter 4, while creating the inventory, some criteria have been set for adopting an aspect in the framework or not. Internships were mentioned within the inventory of 102 aspects, however it was not mentioned often enough in literature and not spread over a variety of sources. Furthermore the level of detail seems too specific to state this as a separate aspect. Internships are covered in several aspects under which: Social return and Knowledge exchange.

7.4. Additional feedback on definitions of the aspects
Participant 2 had a general comment about the ‘classical environmental aspects’. According to participant 2, many of the aspects have already been regulated within the law, and therefore this will not lead to any innovations and real impact towards sustainability. This is a dilemma earlier recognized during the expert interview about environmental impact assessment studies. There the question was raised whether there is enough solution space on these classical environmental aspects to have an impact in terms of sustainability. This consideration has been made in Chapter 4 by defining the initial framework of aspects. It was then decided that these ‘classical environmental aspects’ are the base for such a framework and cannot be left out. Now during the evaluation of these aspects one (water) seemed indeed irrelevant, therefore it has been decided to remove water from the final framework. On the other hand aspects such as Air quality, Emissions and Noise did have some high scores and apparently there is room for sustainability measures beyond regulatory terms on these aspects. In the end it will depend on the specific project circumstances whether there is sufficient solution space to score on these aspects. Also, this framework is no static list; it is the base for a continuous changing framework. For example, Air quality will be on the list for now, however in the upcoming decade there will probably be mostly electrical cars and this aspect might then become redundant. By that time it can be removed from the framework. For now, regarding these classical environmental aspects, no additional chances will be made. Nevertheless the aspect of Water usage will shortly be discussed. Also section 7.6 will come back to the scoring of classical environmental aspects.

In 7.2.2. It was decided to remove water use from the final list of aspects. Some qualitative interpretation of participants on this low score would provide more insight on this decision. Participant 17 commented on this aspect “Water use contributes only as a minor component in the total sustainability score of a tunnel. There are other areas where there is much more to be gained in terms of sustainability.” Participant 5 said about this: “Water on itself is not a problem, as long as you extract and evacuate it in a sustainable way.” Water seems of minor importance, only the way it is used is of importance and that part will be covered by new term ‘frugal use of resources’.
7.5. Implications of low scores for final framework

As the lowest score, Water usage has already gained quite some attention; there are more remarkable low scores which can be discussed. As shown in table 16, after Water usage, Social return, Sustainable leadership, Use of excess soil and Value of soil received very low scores. Therefore for the implications of the results for the final framework, these 4 aspects will be separately discussed.

Table 16 low scoring aspects

<table>
<thead>
<tr>
<th>No.</th>
<th>Aspect</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>19</td>
<td>Water usage</td>
<td>-4.96</td>
</tr>
<tr>
<td>31</td>
<td>Social return</td>
<td>-4.03</td>
</tr>
<tr>
<td>32</td>
<td>Sustainable leadership</td>
<td>-3.65</td>
</tr>
<tr>
<td>21</td>
<td>Use of excess soil</td>
<td>-3.29</td>
</tr>
<tr>
<td>23</td>
<td>Value of soil</td>
<td>-2.77</td>
</tr>
</tbody>
</table>

Social return

Although Social return was no distinguishing aspect, it was a very low scoring aspect. About this aspect comments were made like “This is a nice extra aspect, but in the end it is most important that a sustainable tunnel will be realized. Moreover on a ‘macro-economic’ level it does not matter if the employment comes from the region or somewhere further away” said so by participant 13. Another comment was “Social return is a side-issue. The idea for a sustainable tunnel is to construct as efficient as possible and regional employment only makes the project more expensive.” This way participant 20 putted it. One more comment: “Work should be done by specialists, maybe for some generalist work there can be looked at in the region.” Regarding this last expression the local expertise has already been pointed out in the aspect Local stakeholder involvement. On the basis of the low score and negative comments it is decided to remove Social return from the final list of sustainability aspects. This can easily be done based on these empirical results, since there was no strong literature support for this aspect in chapter 4 either.

Sustainable leadership

Regarding Sustainable Leadership this was, just like some specific tunnel aspect, a relatively new aspect that is not commonly applied. Although it received a low score, one of the non-loaders valued it as most important. “Sustainable leadership is what is needed to actually be able to implement sustainability ambitions” according to participant 9. Also from observations in practice and conversations in the research context, the Rotterdamsebaan, it has been noted that aspects about the implementation and control phase are missing. The question is: ‘In what way will sustainability ambitions be enforced?’ The definition of sustainable leadership was as follows: “Personal managerial long-term commitment to the project’s sustainability goals, activating internal teams as well as the supply chain as a whole.” What is meant with this definition is that a consultant on sustainability who wrote a report presents it to the client and then leaves the project is not enough. There should be personal commitment from the one who proposes the ambitions that this person at least has the intention to stay with the project during the first years of the project execution. Since this definition has not been valued, it should maybe receive a new terminology or definition, however at least one person valued it highly. This aspect will stay in the framework based on practical observations and conversations during the research. Further research on this term and for creating an aspect about the implementation and enforcement of sustainability goals will be recommended.

Use of excess soil and value of soil
These two aspects will be discussed in once. These aspects are relatively new items; these were specifically added to this framework since it is a framework for tunnel construction projects, where underground and soil are important items. 3 aspects specifically mentioning soil were created, these are: Value of the soil, Use of excess soil and Soil Quality. The scores of these new aspects, in combination with water, are shown in the following figure:

Figure 15 Soil and water aspect scores

In this figure the range has been set on -2 to +2 instead of -4 to +4, because no high scoring in the direction of even 2 or 3 was created, and this way a bit more differentiation is pictured. Soil quality has been ranked relatively neutral (surrounding 0) and will stay within the framework. This has been decided because for neutral aspects there is no reason to throw them out. Certainly not since this is quite a new aspect, and compared to the other soil aspect neutral is a relative high score. Regarding Use of excess soil and Value of soil, they received low scores, however they will not immediately be removed either. It is likely that since these aspects are unusual in sustainability criteria lists participant have less strong opinions about them yet. Also these aspects are difficult to translate into monetary terms. While this has already been done for aspects such as energy, materials and CO2 emissions. This could influence the scoring by the participants; they do not know how to value these kinds of items. An item such as Use of excess Soil might in other projects be of insignificant importance, however while constructing a road tunnel project a large amount of soil needs to be removed. This has a large impact and at the same time, brings many possibilities for creative sustainable solutions as well. In literature there is support for this item by experts.

Nevertheless three of these new and specific items might be too much to adopt in the final framework, therefore it has been chosen to merge Use of excess Soil and Value of the Soil into one aspect These aspects will be translated into one more abstract term since it is not clear yet what specifically is most valuable in terms of soil. Therefore the new term will be Sustainable soil management. This will be defined as follows: ‘The tunnel construction project does not alter the capacity of the soil to provide for future needs.’

7.6. Other remarkable scores

All aspects with a remarkable high or low score and contention aspect, important for the interpretation of the perspectives, have been discussed so far. In this section a few aspects, which have not been considered yet, will get some attention. These aspects are:
- Biodiversity
- Hydrological system
Biodiversity
Biodiversity received quite a low score (-1.51). This is remarkable since biodiversity is the only aspect that is a directly linked to one of the greatest environmental challenges. "Two of the most important factors underlying the global environmental crisis are climate change and the loss of biodiversity: as many as two thirds of all species are in danger of extinction" (Sanchez and Murillo, 2012). The identified groups did not reflect this with their scoring. Just as with soil aspects this could be explained because of the lack of a direct link of biodiversity towards social and economic dimensions. To be able to appoint an appropriate value to biodiversity a better understanding of the impact of the loss of biodiversity on social and economic aspects is needed. (Sanchez and Murillo, 2012) It can be assumed that if there is more understanding then it can become a critical aspect in the decision making process for a sustainable road tunnel. Further research is needed on this aspect on how to appoint an appropriate value to biodiversity and how to take it into account in the procurement process.

Hydrological system
The hydrological system does not exist as a sustainability aspect in current sustainability tools. The first time this aspect was mentioned while creating the inventory was during an expert interview on geology. The tunnel construction can have a major impact on the hydrological system: ground water streams can be disrupted with floods as consequence. The total score on this aspect was -0.12. Only group 3 valued this aspect above 0 (2). This was the social group, which looked at the local environment of the project. Breaking ground water streams can have major influence on people and the direct natural environment. The other groups did not specifically see the value of this aspect, however it did not receive a low score either. It seems that this aspect is of particular importance for a sustainability framework for tunnel construction projects, if frameworks and tools will be developed for tunnels in specific people will get more familiar with it.

Educational outreach
This aspect received a low score (-2.01). It can be discussed if this aspect should be part of the sustainability framework or that it should be integrated in a project in another way. For this framework the definition of Educational outreach has been defined as follows: ‘Exchange of information and lessons learned (relating to sustainability practices) with educational and research institutes.’ One participant said to be missing internships; however the idea is that this aspect would cover internships as well. Since Social return has been deleted from the framework the aspect Education outreach becomes more unique within the framework. The definition of Social return was ‘Positive contribution to employment in the region and promote employment of people with poor job prospects.’ It can be interesting for further research to see how these relating aspects can be combined and maybe further specified towards sustainability. Further research could also conclude that these kinds of aspects are not suitable for the sustainability framework.

7.7. Conclusion on framework of aspects
It is hard to define if this initial framework of sustainability aspects for road tunnel construction projects was complete. Most participants did not miss any aspects, which is a positive thing. However some did miss aspects and these, together with the consensus / contention / high and low scoring aspects have been considered. All additional feedback has been processed as well. Finally it has been decided to make several adjustments, which are shown in table 17 on the next page, towards the final framework.
Table 17 Consequences for framework

<table>
<thead>
<tr>
<th>Removed</th>
<th>Added</th>
<th>Redefined</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water usage</td>
<td>Coordination, collaboration and integration in the Supply</td>
<td>Aesthetic and experiential sustainability</td>
</tr>
<tr>
<td></td>
<td>Chain</td>
<td></td>
</tr>
<tr>
<td>Design for disassembly</td>
<td>Operations and maintenance optimization</td>
<td>Landscape integration</td>
</tr>
<tr>
<td>Social return</td>
<td>Sustainable soil management</td>
<td>Definition of Involvement of local stakeholders</td>
</tr>
<tr>
<td>Use of excess soil</td>
<td></td>
<td>Frugal and efficient use of the materials and resources</td>
</tr>
<tr>
<td>Value of soil</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

After these adjustments have been implemented onto the initial framework the final framework of this research can be generated. Overall it can be assumed that this framework is a contribution to the knowledge on sustainable tunnels as well for science as for practice. Building on the feedback of the participants from the industry, it a foundation of a list of useful sustainability aspects for road tunnel construction projects has been created. This list, including definitions, is shown below.

Table 18 Final framework

<table>
<thead>
<tr>
<th>No.</th>
<th>Aspect</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>PROJECT RESILIENCE</strong></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Functional flexibility</td>
<td>The ability of the entire tunnel construction to undergo functional adaptations in the future.</td>
</tr>
<tr>
<td>2</td>
<td>Multifunctionality</td>
<td>Practical combination of multiple functions within the tunnel construction project.</td>
</tr>
<tr>
<td>3</td>
<td>Aesthetic and experiential sustainability</td>
<td>The tunnel should communicate a level of sustainability from an aesthetic and experiential perspective and call attention to sustainable solutions.</td>
</tr>
<tr>
<td>4</td>
<td>Climate adaption</td>
<td>Measures and proactive strategies to mitigate and adapt to potential negative consequences of climate change.</td>
</tr>
<tr>
<td>5</td>
<td>Landscape integration</td>
<td>Allow maximum space for future possibilities of aboveground use and respond to landscape character.</td>
</tr>
<tr>
<td></td>
<td><strong>MATERIALS &amp; RESOURCES</strong></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Frugal and efficient use of the materials and resources</td>
<td>Minimize the amount of materials and resources used.</td>
</tr>
<tr>
<td>7</td>
<td>Origin of materials and resources and environmental impact</td>
<td>Selection of (construction and supporting) materials with consideration for minimal impact on the environment (planet).</td>
</tr>
<tr>
<td>8</td>
<td>Re-use and use of recycled materials</td>
<td>Maximum re-use of components and use of recycled materials and aggregates.</td>
</tr>
<tr>
<td>9</td>
<td>Construction Waste</td>
<td>Minimize (construction) waste and impact thereof on environment.</td>
</tr>
<tr>
<td></td>
<td><strong>ENERGY</strong></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Energy usage</td>
<td>Minimize energy usage over the total project life cycle.</td>
</tr>
<tr>
<td>11</td>
<td>Energy efficiency</td>
<td>Reduction of the amount of energy required for construction and use of the product and services.</td>
</tr>
<tr>
<td>12</td>
<td>Renewable energy sources</td>
<td>Use of (external) renewable energy sources.</td>
</tr>
<tr>
<td>13</td>
<td>Energy production</td>
<td>Use of the tunnel for the production of renewable energy. (Within project scope)</td>
</tr>
<tr>
<td>No.</td>
<td>Aspect</td>
<td>Definition</td>
</tr>
<tr>
<td>-----</td>
<td>---------------------------------------</td>
<td>-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>14</td>
<td>CO2 emission</td>
<td>Minimize CO2 emissions over entire project. (Particularly in construction phase)</td>
</tr>
<tr>
<td>15</td>
<td>Transport</td>
<td>Limit negative impacts of construction-related transportation.</td>
</tr>
<tr>
<td>16</td>
<td>Fossil fuels</td>
<td>Minimize use of fossil fuels.</td>
</tr>
<tr>
<td>17</td>
<td>Water quality</td>
<td>Prevent pollution and minimize impact of construction on groundwater and surface water quality.</td>
</tr>
<tr>
<td>18</td>
<td>Hydrological system</td>
<td>Maintain regular functioning of the (ground)water system and, if necessary, take mitigating measures.</td>
</tr>
<tr>
<td>19</td>
<td>Soil quality</td>
<td>Prevent negative impact on soil quality.</td>
</tr>
<tr>
<td>20</td>
<td>Sustainable soil management</td>
<td>The tunnel construction project does not alter the capacity of the soil to provide for future needs (Smith &amp; Powlson, 2003).</td>
</tr>
<tr>
<td>21</td>
<td>Noise</td>
<td>Minimize noise pollution in the area surrounding the tunnel.</td>
</tr>
<tr>
<td>22</td>
<td>Biodiversity (Flora and Fauna)</td>
<td>Conservation of biodiversity and ecological connectivity, and compensation of potential negative impact as a result of the tunnel construction.</td>
</tr>
<tr>
<td>23</td>
<td>Air quality</td>
<td>Minimize emissions of air pollutants (e.g. smog, NOx)</td>
</tr>
<tr>
<td>24</td>
<td>Toxic materials</td>
<td>Minimize harmful emissions from toxic materials (VOC’s) and resulting health hazards.</td>
</tr>
<tr>
<td>25</td>
<td>Knowledge exchange</td>
<td>Exchange of information and lessons learned (relating to sustainability practices) with educational and research institutes.</td>
</tr>
<tr>
<td>26</td>
<td>Local stakeholder Involvement</td>
<td>Create public support for the project and activate local expertise among future users, local residents and other stakeholders.</td>
</tr>
<tr>
<td>27</td>
<td>Human rights and fair trade</td>
<td>Comply with international labor standards, respect human rights and enforce an anti-corruption policy. (as per the UN Global Compact)</td>
</tr>
<tr>
<td>28</td>
<td>Coordination, collaboration and integration in the Supply Chain</td>
<td>Create easy access for coordination, collaboration and integration of key business processes from end user through original suppliers providing products, services and information that add value for customers and other stakeholders.</td>
</tr>
<tr>
<td>29</td>
<td>Sustainable leadership</td>
<td>Personal managerial long-term commitment to the project’s sustainability goals, activating internal teams as well as the supply chain as a whole.</td>
</tr>
<tr>
<td>30</td>
<td>Sustainable business operations</td>
<td>A culture of sustainable business practices. (At the construction site as well as within the rest of the company)</td>
</tr>
<tr>
<td>31</td>
<td>Life Cycle Cost</td>
<td>The use of life cycle cost approach to stimulate financial considerations throughout the life cycle of the tunnel</td>
</tr>
<tr>
<td>32</td>
<td>Value optimization</td>
<td>Optimize value of the tunnel throughout the life cycle with consideration for all stakeholders.</td>
</tr>
<tr>
<td>33</td>
<td>Operations and maintenance optimization</td>
<td>Ensure operation and maintenance personnel are part of the project planning and development process, including the establishing of commissioning criteria at the onset of a project (WBDG, 2013).</td>
</tr>
</tbody>
</table>
8. Discussion

8.1. Proposal for use of framework and methodology

The methodology can support clients in selecting important sustainability aspects and defining the client’s perspective on a sustainable tunnel. The framework and methodology can be used in two ways:

1. Use four perspectives on sustainable tunnels described in Chapter 6 of this report. If the client can recognize their vision in one of the identified perspectives, the client can use the sustainability aspects belonging to that perspective for implementation in the procurement phase of a road tunnel project.

2. Apply the methodology to the specific project. The methodology can be carried out during a workshop session. Input for this workshop will be the in this research developed framework of sustainability aspects. The client can organize such a workshop at the start of the project either within their organization or by inviting all relevant stakeholders. A properly facilitated workshop will yield:
   − A ranking of the aspects that workshop participants value in a tunnel
   − Consensus aspects; aspects to which workshop participants unanimously describe similar importance
   − Contention aspects, aspects upon which importance workshop participants disagree
   − One or more perspectives or views of a successful sustainable tunnel. These views require work on behalf of the organizer after the workshop, and therefore are not considered direct outputs of the workshop.

Consensus and contention aspects help an organization clarify what participants agree and disagree on. This can provide insight in the existing differences in perspectives towards sustainable tunnels within the organization. It can help the client in the process to finally arrive at a clear perspective on a sustainable tunnel and in defining specific sustainability aspects for the procurement phase.

If the client wants to create a shared ambition towards a sustainable tunnel within the organization, the framework and methodology can be used to make sustainability specific and discussable. The resulting consensus aspects can be used as a basis to start a dialogue. Since there is agreement about these aspects, this is a good starting point for creating mutual understanding. Contention statements are interesting because about strong and conflicting opinions exist regarding these aspects. During the workshop discussions participants will start to recognize each other’s perspective and they can start to share their view and knowledge on specific aspects. This way the participants can define a shared perspective and create a set of sustainability aspects for the procurement phase of their road tunnel construction project.

Besides discussion on the outcomes between participants, the Q-sorting process itself helps to gain understanding on the topic on an individual level. The results of the Q-analysis can be used as a dialogue tool for mutual understanding. Overall, the following advantages of this approach can be identified:
   − This approach can provide insight and understanding about the different perspectives existing within the organization;
   − This approach can be used to involve stakeholders and can lead to stakeholder support;
   − The sorting process helps to identify the individual opinion on a sustainable tunnel;
   − Participants dare to give their own opinion, because they perform the Q-sort individually;
   − This method makes sustainability specific and discussable;
   − It prevents that everyone holds on to their pet subject;
   − Participants often indicate that they enjoyed conducting the Q-sort and value it as instructive (Exel & Graaf, 2005);
The consensus aspects provide a basis for mutual understanding and can be a way forward through conflict (Webler et al., 2009);

The contention aspects can be used as a ground for discussion;

The Q-questionnaire is broadly applicable since it is understood by as well tunnel technical experts as policy makers as people with little experience and knowledge about the project (this has been proven during the execution in chapter 5).

In conclusion, one more application will be proposed. This one is applicable if there is a conflict regarding sustainability within the organization or team that is difficult to solve. Let the whole team together (all at once) take one perspective, and let them, while looking through that perspective, go through all the sustainability aspects. If this has been done, step with the whole team to the second perspective, and so on. This way everybody is obliged to go through all perspectives and the understanding of each other people's preferences grows. It is assumed that this will improve decision-making since everyone considers all aspects from different perspectives. Also since everyone is in the same perspective at the same time they will be more collaborative.

If the client has used the approach, the results of the session can be used to make a selection of aspects for the procurement phase. The next step for the client will be to operationalize the identified aspects in cooperation with experts on those specific subjects. For example: how to make flexibility measurable. After the aspects have been selected it is clear which aspects are important for the client and consequently fit within their identified perspective.

Finally the project delivery organization must decide which aspects are of such importance that they need to be implemented in the minimum requirements of the project and which aspects are suited as EMAT award criteria (or wishes). What conditions exist for operationalizing these aspects is explained in appendix B. Another way of operationalizing the aspects can be to look for award criteria that have been used in other projects by looking into the EMAT library of CROW (2014). However, this process of creating measurement tools for EMAT aspects is beyond the scope of this thesis. This step has consciously been left out because this would limit freethinking and creativity. If the participants would already think about rating systems and legal conditions when defining their ambition and perspective, then they would already limit themselves.

Feedback on approach
The above-described use of the framework and methodology has been proposed to several people. First of all, the participants of the Q-sort have tested the methodology and framework within the context of this research. Thereafter the following feedback has been received:

Project manager environment at Rotterdamsebaan:
- “This approach is indeed a subjective story, which allows you to bring out the true nature (in terms of sustainability) of the person.”

Several participants:
- “It was fun to participate.”

This feedback already validates two of the mentioned advantages of using this approach. After this initial feedback, the approach has been proposed to the Alderman of The Hague, the client of the Rotterdamsebaan, and a Provincial Executive. They made the following remarks:

Alderman of Traffic, The Hague:
- “Very nice that normally incomparable sustainability aspects can be mutually ranked using this methodology.”
- “It is a nice way to get a clear picture for yourself about how you define a sustainable tunnel. It is also valuable that you do not need to dive too deep into detail for every aspect, the simplicity of the impression that is very pleasant.”
“It seems absolutely useable for me individually, as for the policy making process, as well as the involvement of different stakeholders. This because as well experts as people with little knowledge on the topic will be able to use it.”

**Provincial Executive, South-Holland:**

“When working with political parties it is much easier to get everyone on board when you mention specific sustainability parts than when you use the general term sustainability.”

“The development of a method to get stakeholders together at the start of a project to define sustainability, that is very valuable.”

### 8.2. Research limitations

One step of the Q-methodology is the Qsorting, in this research this was done by 27 participants. To perform a Q-sort requires quite some time and effort of the participant. It was estimated that every participant needed 30 minutes to perform the Q-sort. However, since the Q-sorting was done individually it could not be ensured that every participant performed the Q-sorting process in a careful way. If the Q-methodology was performed in person the researcher could have had a better idea about the quality of the Q-sorting process. Nevertheless all Qsorts were fully completed and enough correlation could be discovered which made it possible to identify clear narratives. Therefore it is likely that most participants took the sorting process seriously and completed the Q-questionnaire in the best way they could. Therefore the results of the Q-sorts can be considered as **trustworthy**.

As explained in chapter 5, the diversity of the group of participants in terms of expertise and educational background was quite broad for stakeholders in a technical project. Nevertheless, the **diversity** in gender was extremely low; only one woman performed the research. Although this is a true reflection of the percentage of women working in the tunnel construction industry, for the completeness and generalizability of the perspectives towards sustainable tunnels it would be better to include more women and therewith introduce more diversity into the group of participants. In terms of age diversity, the age of the participants was roughly distributed between age 28 and age 65. This is a fair reflection of the age of stakeholders of the construction supply chain.

The results of the Q-methodology were also used to arrive at a ranking of the list of aspects. It is not a standard application of the Q-methodology to create a ranking within the Q-sample. Within the output files of the PQmethod no such ranking was automatically generated. However it has been chosen to indirectly deduce a ranking from the outcomes of the factor analysis. It should be kept in mind that this ranking has not been created by a representation of the population, but by stakeholders from the construction supply chain with various backgrounds and expertise. Besides, to achieve this ranking only the total scores on the four identified perspectives were taken into account since the ranking was based on the z-scores of the perspectives. Thus the non-loaders ranking was not considered. It could be the case that one of the non-loaders did not seriously complete the q-sort and therefore arrived at a deviating score. If this was the case then it is wise that this score was not used to determine the ranking. However, it is likely the non-loaders participants did take the Q-sort seriously, but their unique view towards the topic is the reason for the deviating Q-sort. In that case it is a limitation for the research that this person’s ranking has not been considered. If all participants ranking would be equally important for the final ranking then the AHP method, which has been discussed in chapter 2, would be more suitable. However in this research the ranking has been a side product and the Q-methodology provided much more insight than just a ranking. For the future, clients or PDO’s could combine both methods for optimal outcomes.

Q-methodology results cannot be **generalized** to the entire population. Fortunately, this has never been the purpose of this research. This research was focused on the tunnel construction
supply chain. As shown in chapter 5 a fair representation of the stakeholders in a tunnel construction project has participated in the research. This representation gives more relevant insights than a general population view. Therefore the Q-methodology and choice of participants seems right.

Although the context of this research was the Rotterdamsebaan, the research aimed at the creation of project independent sustainability aspects. The final sustainability framework seems applicable for road tunnel construction projects in general. There seems no indication that participants were bounded by the particular project they were working on or most familiar with. This can assumed because many aspects that would not be applicable anymore for the Rotterdamsebaan, still received a high ranking by participants who are involved in that project. Furthermore, during the entire research, both during interviews as for the Q-sort, it was ensured that the questions asked were always pointed to road tunnels in general. Therefore it can be assumed that the final framework is applicable road tunnel construction projects and that the developed sustainability aspects are project independent.

Regarding the perspectives, it should be kept in mind that these perspectives represent current perspectives. This means they provide relevant insights at this point in time. However, the integration of sustainability in practice as well as the research on this topic is constantly evolving. Therefore these perspectives are likely to change as well, just like people constantly changing learn and change their opinions. Thus a limitation for the outcome of this research is that the perspectives are a static result, which is mainly relevant at this moment in time. Thus it cannot be ensured that the results are will still be valid or the same in a year from now. To coop with these limitations an approach has been proposed towards clients to apply this framework and methodology in their project when insights on the topic are needed. By not using the current perspectives but by identifying perspectives on their particular project in that specific moment, the outcomes will lead to more up to date insights.

The question to ask regarding the reliability of the research is if the research could be done in the same way and with the same results. The answer for this research is for a large extent affirmative. All sources that have been used for the creation of the inventory are mentioned in the literature list and which aspects have been adopted in the inventory has been highlighted in the Exel model in the Appendix E. Therefore it is likely that the inventory could be created in the exact same way. Regarding the selection from the inventory to the initial framework (Q-sample) it becomes a bit more difficult. This selection is partly based on criteria, which have been explained and thus could be re-applied. However while merging certain aspects to one aspect the final definition of the aspect has been a personal consideration. Nevertheless, this deviated little from the original definitions of the sub aspects and therefore it is likely that also this step can be repeated in the same way. The interpretation of the results required knowledge and experience of the researcher. Consequently for defining narratives on perspectives it is essential to have some experience in this research area to be able to recognize the coherence between individual Q sorts and to create a clear narrative. If another researcher would perform this step the basic narrative and scoring of aspects will be probably the same, however the names of the perspectives and the interpretation of the scores will certainly be different. The same goes for chapter 7, the implications of the q-method for final framework. This chapter was besides the results of the q-methodology, based on personal judgment and observations from practice. Another researcher could have had different observations from practice and could have arrived at different literature and experts, which could have led to different adjustments of the final framework. Nevertheless, asking for feedback on the aspects by the participants lead to a check on the interpretation of the researcher’s observations. These checks add to the validity of the personal interpretations. Regarding the interpretation of the results for the final framework, it is likely that another researcher would make the same conclusions on the high and low scores. Overall, the research could be carried out in the same way and will probably lead to a large extend to the same outcomes.
The completeness of the developed framework cannot be ensured. The reason for this is since the inventory was limited because of time limitations for a master thesis research. This inventory could always have been more elaborated. Although triangulation of data from different sources did increase the validity of the data collection, even more sources could have been explored and more interviews could have been conducted. Also an in depth literature research to support each aspect could have been done; however this would not have contributed to extra value for the input for the Q-methodology. This would only have contributed to the quality of the final interpretation and evaluation of the framework.

The initial framework has been adjusted after feedback from 26 participants. This re-defining, adding and removing of sustainability aspects led to the translation of the initial framework to the final framework. More iterative steps could be made to further test the reliability and validity of the current framework. However a framework that tries to catch such a complex issue will never be complete. After the feedback of the participants it can be assumed that this framework is comprehensive and forms a foundation to continue built on when new developments and insights arise.

When selecting the Q-methodology as the right methodology to use in this research it was also chosen to create a concourse, in this case a broad inventory of sustainability aspects, to finally arrive at a Q-sample as input for the methodology. Many sources were scanned with the purpose to create this broad inventory. Scanning is the way to arrive at a Q-sample and also the only way in which studying so many sources was possible within the timeframe of a master thesis research. Consequently, this approach was applied to check current tunnel projects on sustainability aspects. Later on in the research, it was discovered that these projects where not in comparable stages of applying sustainability aspects in their project. There was one specific project that seemed to be in a much more advanced stage of sustainability applications in a tunnel project than was apparent in the data collection phase. During the last months of the project someone at the Rotterdamsebaan visited the Crossrail tunnel project and received a report on sustainability measures within this project. Then it became clear that in the Crossrail project they already have an extensive approach towards sustainability including an entire responsible sustainability committee. Although this approach is still quite complex and one clear perspective is lacking, the developments are further developed than was stated in the problem statement of this research. This project currently makes an exception within this industry. If this would have been discovered earlier on in the research, then this project could have been used as a case study. Therefore this will be added to the further research recommendations.

8.3. Placing the research in perspective

8.3.1. Academic perspective

This thesis contributes to the scientific community in several ways. First, the inventory that has been created puts together all aspects related to sustainability in tunnel construction projects. Other scholars working on this topic could directly make use of this inventory. The next delivery, the developed framework with sustainability aspects, is a comprehensive framework which can function as a foundation to continue to build on and can be further tested by other researchers. At the start of this research it was stated that no overview of possible (EMAT) criteria for sustainability in construction projects were available and no literature was found on tunnel construction projects and EMAT sustainability criteria specifically. By identifying 33 sustainability aspects especially applicable for road tunnel construction projects this knowledge gap has been reduced.
Furthermore a **new approach** was proposed in which the developed framework and the Q-methodology can be used to define a perspective on sustainability. This approach can be applied in other industries or within this industry for different purposes. For example, the dean of the faculty of Civil Engineering could use the approach to establish a perspective on sustainability towards research and education within this faculty. A workshop could be organized with some faculty staff and based on the outcomes of the workshop a clear definition of sustainability within the faculty could be established. This definition would make sustainability more specific and tangible for as well the faculty staff as students. The workshop itself could help to create greater understanding on the topic and mutual understanding between researchers of the different fields. As a result this new perspective can lead to a definition of sustainability for this particular faculty and could be adopted into the faculty’s policy and goals.

Besides the inventory, framework and approach, some smaller contributions were made. Especially the **trade-offs** that have been made during the research and which have been described in this report can be helpful for other students or researchers. For instance, the description of the methodology trade-off between the AHP and the Q-methodology can be insightful, just like the trade-off on different Q-methodology tools and models. Lastly, the Q-**questionnaire Excel model** that was further improved based on the foundation of another master thesis student, can now be used and further built on by other students or researchers.

### 8.3.2. Practical and societal perspective

As was described in the introduction of this thesis, the construction industry has a major potential to contribute to sustainable development by addressing social, environmental and economic challenges. To achieve significant improvements clients need to take responsibility and set clear and ambitious perspectives towards sustainability in large construction projects, such as road tunnels. Only if clients will require this, then the market will follow and devise sustainable solutions. This research has developed an approach to support the client in defining their perspective and select aspects to take sustainability into account during the procurement phase of a road tunnel construction project. This can contribute to achieving progress in sustainable development within the construction industry.

The developed framework can be used in practice. Clients of future tunnel construction projects can take this framework as a basis to select sustainability aspects for their particular project. They can either use the current perspectives to gain greater insight in the issues or they can organize the in this research proposed workshop.

Conducting the workshop in the setting of a road tunnel construction project can help to achieve greater mutual understanding between stakeholders. In such complex projects as tunnel projects, many different stakeholders with different perspectives need to cooperate. By identifying these different perspectives and providing a base for discussion, sustainability becomes specific and tangible and this can contribute to a greater understanding and achieving sustainability goals.

### 8.3.3. Personal perspective

A very interesting personal insight is that there exist as many perspectives towards a sustainable tunnel as there are stakeholders. In the research, there were no two questionnaires exactly the same. The Q-methodology in the sustainability indicators debate also appeared to be very interesting because it makes aspects comparable that are normally not comparable. Furthermore it makes a complex concept very specific and tangible. Especially political figures such as the Alderman and Provincial executive valued this very much since the concept of sustainability is ‘contaminated’ some political parties are always pro and others have negative connotations with the term. To make the container concept specific and the sustainability aspects mutually comparable was considered as very valuable. I even started to use it for myself in other areas of my life. For example, regarding clothing I asked myself: ‘What
Tunnel Visions on Sustainability

8.3.4.  Personal perspective on process and document expert team sustainability

My internship at the Rotterdamsebaan allowed me to experience the procurement phase of a tunnel construction project from the side of the project delivery organization. It has been very
educational to be part of the procurement & contracting team. Besides, it was very interesting to function as a middleman between the external expert team sustainability and the implementation team of the Rotterdamsebaan. This new approach to the procurement process has been interesting to follow from both sides. An in depth analysis and evaluation of this process involving an expert team sustainability in a procurement process could be an interesting research in itself. This analysis was no part of my research, however I will now give a short personal reflection on it.

First of all, during the meetings I attended from the expert team Rotterdamsebaan it became clear that every expert understood the concept of a sustainable tunnel differently. Especially when choices on aspects needed to be made, each persons ‘pet topic’ became clear. I recognized that it is difficult for experts to take on another perspective. To prevent that experts constantly fall back on their favorite topic, the in this research proposed approach could be helpful as a communication tool. Also the idea of switching perspectives could be insightful. With this I mean taking on one perspective with the whole team at once and going through all aspects. Then the whole team takes the second perspectives and they try to see the value of all aspects through this perspective etc. This could help to arrive at a mutual vision.

Currently the experts of the expert team have not influenced each other’s perspective. This became clear of the results of the Q-methodology. 6 experts of the expert team have participated and they were equally divided over three different perspectives.

The framework developed by the expert team contained 9 main aspects. However many of the aspects were divided into sub aspects, in my framework these aspects would have been defined as many more aspects. For example Multifunctionality and Flexibility has been considered as one aspect whereas I think they are very different and should be separated. Another aspect of their framework ‘Natural integration’ is covering Water, Soil, Flora and Fauna and Climate. As can be seen from my analysis these aspects have been rated very differently. Therefore I think it would be better to separate these aspects as well, and then it could be decided to keep some aspects and remove others from the final framework. Another remarkable difference is that I have chosen to include very specific tunnel aspects such as Use of excess soil and Influence on surface area. Although these were not ranked very high, I think it is useful to create specific tunnel aspects for general guidelines for tunnels. This way these guidelines will be most applicable for tunnel projects and this way the framework will be distinctive from general infrastructure guidelines, such as the DuurzaamGWW.

One aspect I would add to the framework developed by the expert team is an aspect on Sustainable leadership to ensure the implementation on the ambitions or the experts themselves could commit to the project for a longer period of time. Participants from this research indicted that they missed the aspect Supply chain integration. I think this would also be a good aspect to take into account in the expert team framework.

Overall the document developed by the expert team Rotterdamsebaan seems far-reaching and ambitious. It covers many of the relevant sustainability aspects for tunnel construction projects.

From this process I enjoyed to experience all discussions and debates on the topic between the experts team, the project delivery organization and the tenders. The same kinds of discussions were present during my committee meetings. I think that these conversations and knowledge exchange already contributes to the transition towards a more sustainable tunnel construction industry.
9. Conclusions

The main goal of the research was to develop and rank sustainability aspects that can secure sustainability within the procurement process of road tunnel construction projects and to propose an approach to support clients in identifying their perspective on a sustainable tunnel and translating this into a selection of relevant sustainability aspects for their specific project.

This has led to the definition of the following main research question:

- How to incorporate sustainability into the procurement phase of a road tunnel construction project with regard to sustainability aspects and their selection process?

This research question has been divided into several sub questions. These sub questions are directly connected to the three problem statements and three objectives. The structure of the entire thesis has been based on the framework displayed below. This concluding chapter will be structured according to the three research objectives.

Section 9.1 will pursue the results of the first objective: to create a framework of relevant sustainability aspects for securing sustainability in the procurement process of tunnel construction projects.

Section 9.2 will further examine the second objective: to identify current perspectives on sustainable road tunnels.
The results on the third objective will be described in section 9.3: **to develop an approach that can support clients in selecting and ranking sustainability aspects, based on the specific circumstances of the project and their perspective on sustainable road tunnels.**

In section 9.4 the main research question will be answered.

### 9.1. Conclusion on the framework of sustainability aspects

The creation of the framework was done based on three sub questions. The first sub question ‘**What sustainability aspects for tunnel construction projects can be extracted from the literature, expert interviews and reference projects?**’ was answered by the creation of an inventory of 102 aspects. The second sub question ‘**Which set of sustainability aspects can be used as an initial framework?**’ led to a filtering resulting in 35 aspects that formed the Q-sample as input for the Q-methodology. With the results of the Q-methodology and the additional comments provided by the participants of the Q-methodology, the following adjustments for the initial framework were identified:

Table 19 Implications for framework

<table>
<thead>
<tr>
<th>To remove</th>
<th>To add</th>
<th>To redefine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water usage</td>
<td>Coordination, collaboration and integration in the Supply Chain</td>
<td>Aesthetic and experiential sustainability</td>
</tr>
<tr>
<td>Design for disassembly</td>
<td>Maintenance free design</td>
<td>Landscape integration</td>
</tr>
<tr>
<td>Social return</td>
<td>Sustainable soil management</td>
<td>Definition of Involvement of local stakeholders</td>
</tr>
<tr>
<td>Use of excess soil</td>
<td></td>
<td>Frugal and efficient use of the materials and resources</td>
</tr>
<tr>
<td>Value of soil</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

These adjustments have been applied to the initial framework that originally consisted out of 35 aspects. The process of implementing these alterations was at the same time the answering of the third sub question ‘**Which framework of sustainability aspects and which ranking can be used for the procurement phase of road tunnel construction projects?**’ The final framework consists of 33 sustainability aspects, which can be considered as a complete set of sustainability aspects for road tunnel construction projects. The final framework looks as follows:
The problem that was underlying this objective was the lack of sustainability criteria for road tunnel construction projects in as well literature as in practice. By identifying this framework of aspects this knowledge gap has been reduced.

9.2. Conclusion on the current perspectives

The second objective was to identify current perspectives on sustainable road tunnels. This answers the following sub question: ‘What are the current perspectives on these sustainability aspects for road tunnel construction projects?’ The application of the Q-methodology and the interpretation of the results resulted in four perspectives on sustainable road tunnels. These four perspectives represent the different views of how stakeholders from the construction supply chain currently perceive a sustainable tunnel. Furthermore it describes how a sustainable tunnel is defined from a specific perspective and what sustainability aspects would accompany this perspective during the procurement process.

The Energy Perspective: “Minimize energy-use, reduce carbon emissions and ensure efficiency over the project life cycle.”

The Energy perspective assesses the sustainability of tunnel designs based on Energy use, Energy efficiency, Long-term design and Life cycle cost. The Energy perspective was shaped by the questionnaires of five participants with an analytical background. Trade-offs between aspects were made with a long-term perspective and materials and energy should be used as efficient as possible. Participants sharing this perspective value aspects that are measurable and quantifiable, such as CO2 emissions and Air quality. Energy is the most important driver, in terms of quantity (total use) and quality (production method -Renewable energy and Energy efficiency). To achieve a sustainable tunnel, an efficiency approach is taken towards all aspects within the construction process. Therefore Multifunctionality does not fit within this perspective, since it is questionable if this necessarily leads to a sustainable tunnel. This perspective would take the following sustainability aspects into account during the procurement process (in order of relevance):

Figure 17 Final framework of aspects
– Energy efficiency
– Renewable energy sources
– Life Cycle Cost
– Air quality
– Energy use
– Energy production
– Material and resource use
– CO2 emissions

➢ The Resilience Perspective: “Optimize functionality and value over the project life cycle.”
The Resilience perspective focuses on processes and values systems thinking. The shared belief
of holders of this perspective is that a sustainable tunnel should be optimized for its
functionality. According to this perspective, Value optimization is about maximizing positive
effects and creating added value to the project with an emphasis on process and LCC thinking.
The perspective, defined by six participants with a predominant (civil) engineering background,
considers optimization problems as interesting challenges. For example, these participants see
Multifunctionality as a technical optimization of smart solutions. This group would define a
sustainable tunnel as a tunnel that has maximum functionality and value. This perspective
would take the following sustainability aspects into account during the procurement process
(in order of relevance):
  – Life cycle cost
  – Multifunctionality
  – Value optimization
  – Influence on surface area
  – Functional flexibility
  – Design for disassembly

➢ The Social Perspective: “Consider local stakeholders and the direct project environment.”
The Social perspective regards a sustainable tunnel as a tunnel that has been constructed in
close cooperation with local stakeholders and with maximum attention for the (changing)
project surroundings. Furthermore there should be more functionality to the project than just
a road. The perspective was shared by six participants who had different educational
backgrounds, yet were mostly project managers. The latter could clarify the emphasis on
sustainability as a people matter. Their core belief is that if stakeholders are heard and safe,
they will value and even contribute to the project. Consequently there will be less obstruction
to the project, which makes the tunnel construction project more sustainable. This perspective
would take the following sustainability aspects into account during the procurement process
(in order of relevance):
  – Functional flexibility
  – Local stakeholder involvement
  – Multifunctionality
  – Human rights and fair trade
  – Air quality
  – Life cycle cost
  – Value optimization

➢ The Transition Perspective: “Prevent harmful effects on people and the planet now and
on the long-term.”
The Transition perspective, shared by five participants without any purely engineering
background, considers sustainability with impact on the project surroundings: on the people
and their environment (planet). ‘A sustainable project is a project without toxics and chemicals
and without environmental harms.’ It also considers the effect on people’s health, sight,
perception and experience. Sustainability demands an entirely new approach according to the
participants that share this perspective. This group looks into the future and within this future
there is no room for profit aspects. It is about re-thinking and re-designing in many ways.
Therefore *Functional flexibility* is viewed as the most important aspect. A demand for more control from the local community is reflected in the high scoring aspects such as *functional flexibility*, minimum *influence on surface area*, and *renewable energy sources*. In literature coherence of these aspects has been found the development of transition towns. This perspective would take the following sustainability aspects into account during the procurement process (in order of relevance):

- Functional flexibility
- Influence on surface area
- Toxic materials
- Renewable energy sources
- Visual sustainability and experience
- Recycling and re-use
- Energy use

The identification of these perspectives shows that there are as many perspectives as stakeholders in a tunnel construction project; not one Q-sort was exactly the same. However, the coherence of certain aspects did show that certain collective perspectives could be identified. Mapping these perspectives itself is already worthful for a greater understanding among stakeholders in the construction supply chain. Furthermore, these perspectives could help the client in identifying their perspective and selecting a range of sustainability aspects. However, if the client does not recognize itself in one of the current perspectives, the client could apply this approach to their specific project. This approach will be explained in the next section.

### 9.3. Conclusion on the approach

The third objective was to develop an approach that can support clients in selecting and ranking sustainability aspects. To this objective belongs the following sub-question:

*Which approach can support a client in selecting and ranking sustainability aspects, based on the specific circumstances of the project and their perspective on sustainable road tunnels?*

First, the ranking as created during this research will be presented. Secondly, the approach itself will be described.

**Ranking of the sustainability aspects**

A ranking has been generated out of the four perspectives within the current construction supply chain. This ranking is based on the opinion of experts from the construction supply chain with some knowledge and/or experience in sustainability, covering every position of the supply chain. This ranking can be insightful for a client for selecting the relevant sustainability aspects for their specific project.
Table 20 Ranking of initial framework of sustainability aspects

<table>
<thead>
<tr>
<th>No.</th>
<th>Aspect</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>34</td>
<td>Life Cycle Cost</td>
<td>3.83</td>
</tr>
<tr>
<td>2</td>
<td>Multifunctionality</td>
<td>3.44</td>
</tr>
<tr>
<td>12</td>
<td>Energy efficiency</td>
<td>3.26</td>
</tr>
<tr>
<td>1</td>
<td>Functional flexibility</td>
<td>3.21</td>
</tr>
<tr>
<td>11</td>
<td>Energy usage</td>
<td>2.4</td>
</tr>
<tr>
<td>26</td>
<td>Air quality</td>
<td>2.39</td>
</tr>
<tr>
<td>8</td>
<td>Origin of the materials and resources</td>
<td>2.26</td>
</tr>
<tr>
<td>13</td>
<td>Renewable energy sources</td>
<td>1.97</td>
</tr>
<tr>
<td>7</td>
<td>Material and resource usage</td>
<td>1.7</td>
</tr>
<tr>
<td>25</td>
<td>Noise</td>
<td>1.52</td>
</tr>
<tr>
<td>5</td>
<td>Influence on surface area</td>
<td>1.5</td>
</tr>
<tr>
<td>27</td>
<td>Toxic materials</td>
<td>1.24</td>
</tr>
<tr>
<td>10</td>
<td>Construction Waste</td>
<td>1.15</td>
</tr>
<tr>
<td>15</td>
<td>CO2 emission</td>
<td>1.13</td>
</tr>
<tr>
<td>9</td>
<td>Recycling and re-usage</td>
<td>0.94</td>
</tr>
<tr>
<td>4</td>
<td>Climate adaption</td>
<td>0.84</td>
</tr>
<tr>
<td>35</td>
<td>Value optimization</td>
<td>0.69</td>
</tr>
<tr>
<td>20</td>
<td>Hydrological system</td>
<td>-0.12</td>
</tr>
<tr>
<td>14</td>
<td>Energy production</td>
<td>-0.18</td>
</tr>
<tr>
<td>29</td>
<td>Local stakeholder involvement</td>
<td>-0.23</td>
</tr>
<tr>
<td>18</td>
<td>Water quality</td>
<td>-0.38</td>
</tr>
<tr>
<td>22</td>
<td>Soil quality</td>
<td>-1.01</td>
</tr>
<tr>
<td>33</td>
<td>Sustainable business operations</td>
<td>-1.02</td>
</tr>
<tr>
<td>16</td>
<td>Transport</td>
<td>-1.06</td>
</tr>
<tr>
<td>30</td>
<td>Human rights and fair trade</td>
<td>-1.15</td>
</tr>
<tr>
<td>17</td>
<td>Fossil fuels</td>
<td>-1.26</td>
</tr>
<tr>
<td>24</td>
<td>Biodiversity</td>
<td>-1.51</td>
</tr>
<tr>
<td>28</td>
<td>Educational outreach</td>
<td>-2.01</td>
</tr>
<tr>
<td>3</td>
<td>Visual sustainability and experience</td>
<td>-2.26</td>
</tr>
<tr>
<td>6</td>
<td>Design for disassembly</td>
<td>-2.57</td>
</tr>
<tr>
<td>23</td>
<td>Value of soil</td>
<td>-2.77</td>
</tr>
<tr>
<td>21</td>
<td>Use of excess soil</td>
<td>-3.29</td>
</tr>
<tr>
<td>32</td>
<td>Sustainable leadership</td>
<td>-3.65</td>
</tr>
<tr>
<td>31</td>
<td>Social return</td>
<td>-4.03</td>
</tr>
<tr>
<td>19</td>
<td>Water usage</td>
<td>-4.96</td>
</tr>
</tbody>
</table>
Approach
Besides the direct use of the outcomes of this Q-methodology, the methodology can also be used as an approach to support the client in selecting relevant sustainability aspects for their specific project. This approach can be applied during a workshop. The difference between this approach and the regular application of the Q-methodology is that the first 3 steps of the Q-methodology can be skipped. Because input for this workshop will be the, in this research developed, framework of aspects. The client can organize this workshop at the beginning of a project and either invite all project stakeholders or the people within the project organization. A properly facilitated workshop will yield:

- A ranking of the aspects that workshop participants value in a tunnel
- Consensus aspects; aspects to which workshop participants unanimously describe similar importance
- Contention aspects, aspects upon which importance workshop participants disagree
- One or more perspectives or views of a successful sustainable tunnel. These views require work on behalf of the organizer after the workshop, and therefore are not considered direct outputs of the workshop.

These consensus and contentation aspects can be used as a support and stimulus for a dialogue between stakeholders. If the client wants to create a shared definition within the organization the consensus aspects can be used as common ground for the start of the dialogue since there is agreement and understanding on these aspects. Then the contention aspects can be a basis for discussion. This way the output of the workshop can be used as a dialogue tool to finally arrive at a project specific selection of sustainability aspects and a project specific definition of a sustainable tunnel.

Last but not least, the developed Excel model is also an outcome of the research; this questionnaire model could be used if it would not be possible to get all the stakeholders physically together. However for the purpose of defining a definition and selecting aspects it is recommended to perform it in physical presence. The questionnaire model could also be used by future Q-researchers.

9.4. Conclusion on main research question

How to incorporate sustainability into the procurement phase of a road tunnel construction project with regard to sustainability aspects and their selection process?

Sustainability can be incorporated in the procurement phase of a road tunnel construction project by using the developed framework of 33 aspects. This framework can be used in two different ways:

1. First, it can be used to gain insight in the possibilities for incorporating sustainability in road tunnels. The client can directly select sustainability aspects from the framework. The framework accompanied with the current perspectives and ranking on sustainable tunnels, can give more insight on the current views towards sustainable tunnels. If the client identifies itself with one of the outlined perspectives, the client can directly implement the sustainability aspects belonging to that perspective in the procurement phase of their road tunnel project.

2. A second way of using the framework is to use it as input for the approach and use the output of this approach as a dialogue tool to arrive at a final selection of sustainability aspects for their specific project. Based on this selection the client can create a project specific definition of a sustainable tunnel.

The framework with 33 sustainability aspects for road tunnel construction projects can be considered as a comprehensive and applicable framework. This framework forms a basic set of aspects that can be adapted and improved over time by experts and experience. The proposed
approach shows the applicability of the framework with sustainability aspects and can support clients and PDO’s in selecting and ranking sustainability aspects for their specific project. The identified perspectives may lead to more understanding on sustainability within the industry by making sustainability more explicit, tangible and therewith discussable. Furthermore it can also help individuals to better understand their position towards sustainable tunnels and create more understanding between stakeholders in the tunnel construction supply chain, which may fasten the transition towards a sustainable society.
10. Recommendations

Initially these recommendations are designed for clients of road tunnel construction projects. In the ideal world, the client of a tunnel construction project gives attention to sustainability at the start of a project. This way the client defines the sustainability goals and the project delivery organization subsequently adapts these goals and translates them into the procurement process. The tenderer will arrive at specific solutions for the defined sustainability ambitions. Nevertheless, in the real world, the client’s ambitions toward sustainability within tunnel construction projects, is usually not specified at the start of the project yet. This was the case in the context of this research; at the Rotterdamsebaan. In such cases these recommendations are applicable for project delivery organizations instead of clients.

Furthermore, specific recommendations on how the project organization Rotterdamsebaan should incorporate sustainability into their procurement will be made. This will be done because this organization provided the opportunity to perform this research in the context of that project.

Lastly, recommendations for further research are identified.

10.1. Towards clients of road tunnel construction projects

Establish a clear and ambitious vision on sustainable tunnel

- Establish a clear ambition and definition of a sustainable tunnel based on the selection of sustainability aspects, as early in the process as possible. The developed framework, perspectives and approach can support the selection process.
- Do not be limited by currently existing measurement tools, certificates and EMAT aspects when defining the project ambitions. This would limit the creation of a true and distinctive sustainability ambitions for the project, and on the long run this will not contribute to the transition towards more sustainable construction.
- Dare to set new and ambitious goals towards a sustainable tunnel. If this ambition is defined in the procurement criteria then the tenderers are stimulated to create innovative and sustainable solutions.
- Value sustainability significantly as an award criterion to stimulate innovation in the market and to contribute to future project exceeding developments as well.
- Be a game changer and procure only on sustainability. Set a fixed price and take only sustainability as an EMAT award criterion during the procurement phase, specify the concept with sustainability aspects. This way sustainability becomes the only measurement in comparing the different tenders and therefore of main importance for the project.

Operationalize and monitor aspects in cooperation with experts

- Involve experts on the themes of the selected aspects to operationalize the aspects and to control and monitor the execution of the sustainability goals during the implementation phase.
- Leave as much room as possible (functional specification) within the operationalization of the aspects. This way the tenderers can devise innovative and creative sustainable solutions.
- Base the choice of aspects on the impact that they might have on the success for the specific project. To take sustainability seriously into account in the weighing of the criteria the project specific wishes towards sustainability should be clearly defined.

Apply the proposed approach at the start of a project

- When defining the aspects, use the approach that is proposed in this research. The new EMAT procurement procedure requires a new approach where more communication in the preparation phase of the project between all stakeholders is needed to arrive at a clear perspective and sustainability objectives. For this purpose a workshop, using the developed framework of sustainability aspects, is recommended.
- Plan a session before the start of the project
- Plan a full day, with at least 12 people (to arrive at 3 perspectives with 33 criteria)
- Involve as many different stakeholders with a relevant view
- Use the output of the workshop as a dialogue tool to arrive at a clear definition, mutual understanding and project specific sustainability goals

- Execute the approach during the competitive dialogue phase with the tenderers, if it was not possible at the start of the project. It would be very interesting to see how the different tenderers view a sustainable tunnel and the Q-method outcomes can be used as input for the competitive dialogue.

**Implement sustainability in the entire process and be open about it**

- Share all experiences with incorporating sustainability in the procurement of a tunnel construction project with other clients and PDOs to contribute to the urgent transition to a sustainable society.
- Integrate sustainability not only in the procurement phase but also in the total project and process. This includes: the ambition, specification, and EMAT award criteria, choice of contract and in the organization.

**Use the framework for further developments in guidelines for sustainable tunnels**

- Use the framework with sustainability aspects that is developed in this research as a basis for the development of an assessment tool or general guidelines for tunnel construction projects.
- Ensure that the development of this tunnel sustainability assessment tool or guidelines will be an integrated effort towards one unified tool. This way it can be avoided that a wide diversity of assessment tools will be developed side by side, like what has occurred in the building industry. If the focus lays on the development of one tool, knowledge can be bundled and this tool can continuously develop and be ground for dialogue between stakeholders in this industry. This bundled effort should at least be at country level, it would be even better if this development could be raised to a European or worldwide level.

**10.2. Recommendations for the project organization Rotterdamsebaan**

Since the Rotterdamsebaan is already in an advanced stage, some earlier mentioned recommendations are not applicable for this project anymore. Nevertheless still some recommendations can be made towards the project organization.

- Create, as soon as possible, a clear perspective on what a sustainable Rotterdamsebaan tunnel is and what are desired outcomes by the project organization. Define specific sustainability aspects in coherence with this ambition and communicate this with the tenderers during the competitive dialogue phase.
- Select these aspects from the sustainability framework from the expert team sustainability Rotterdamsebaan. If an aspect is missing to make the ambition complete, remaining aspects could be selected from the framework developed in this research.
- If it would not be possible anymore to define a specific sustainability ambition, due to the advanced stage of this project, then adopt a definition of what a sustainable Rotterdamsebaan would look like based on the identified perspectives. For example, the Energy Perspective: “A sustainable tunnel project, in the case of the Rotterdamsebaan, focuses on clean energy and efficiency.” This will result in a selection of the following sustainability aspects: Energy efficiency, Renewable energy sources, Life Cycle Cost, Air quality, Energy use, Energy production, Frugal and efficient use of the materials and resources and CO2 emissions.
- This way tenderers can focus their creative power and energy on developing effective sustainable solutions on these specific aspects, which is much more effective then if they are developing tons of sustainability ideas without any direction.
Further develop the framework and approach

- Research the applicability of this final framework for other countries;
- Further test the completeness of the final framework;
- Further specify the framework for different tunnel types;
- Evaluate the Crosslink tunnel construction project on their sustainability goals and how it was incorporated in the procurement phase and implementation;
- Develop a new software program for PQmethod, which is more modern and user-friendly than MS Dos. With the new software or application the Q-methodology will become more attractive to use.

This has been an explorative research, further research is recommended on specific aspects

- Conduct further research into aspects specific on Sustainable soil management.
- Create new measurement tools for popular aspects such as: Functional flexibility, Multifunctionality, Value Optimization and Visual sustainability and experience.
- The aspect of Biodiversity received a low scoring while it is the only aspect directly linked to a major environmental problem. It was assumed that if there is more understanding about biodiversity and the effects on social and economic dimensions, then it can become a critical aspect in the decision making process for a sustainable road tunnel. Therefore it is recommended to conduct further research on how to appoint appropriate value to biodiversity and how to take it into account in the procurement process.
- It could be interesting for further research to see how aspects on Education, Knowledge retention and Social return can be combined and maybe further specified towards sustainability. Further research could also conclude that these kinds of aspects are not suitable for adoption in the sustainability framework.
- Evaluate the use of the developed framework and proposed approach in the procurement phase of a tunnel construction project.

Be innovative with procurement procedures

- In this research EMAT procurement has been the point of departure, however it is not ensured that this mechanism is the best way of procuring to arrive at a sustainable tunnel. New ways of procurement could be researched and compared to find out which accommodates the sustainability ambitions best. An interesting direction for further research could be what kind of procurement mechanism could compare different perspectives/focuses within sustainable tunnels. For example that tenderer one could...
take the *Energy approach*, while tenderer two has a *Social perspective on sustainability*. This new mechanism should enable the client to make trade-offs between those different perspectives. This way each tenderer could specialize in specific sustainability measures and the market becomes more differentiating and competitive this would stimulate and fasten research that could have a positive impact on sustainability measures on the long run. Defining a certain fixed and substantial budget for sustainability could do this. And challenge the market to devise the most sustainable tunnel within this budget.

- Research into the development of the highly ranked *Life Cycle Cost* aspect in relation to the EMAT award mechanism. This particular aspect could already cover many other sustainability aspects. This way EMAT might not be relevant anymore or a separation of aspects covered by LCC and other could be made.


Ondergrondse. (2014). Scan duurzame tunnels. unpublished search result, Delft University of Technology.


Appendix A : Glossary

Award criteria
The list of key criteria that is used to assess a supplier’s tender.

Authority
The public body buying goods or services.

Centroid method
A way to extract factors from the data of the Qsorts. This is a part of the PQmethod program.

Competitive dialogue procedure
The process, under the procurement regulations that allows the procuring party to discuss different options with bidders before selecting a solution. It can only be used in certain particularly complex contracts where technical solutions are difficult to define or where discussion of the best legal or financial structure is needed. The competitive dialogue procedure can only be used when the open and restricted procedures are not suitable for the procurement.

Concourse
A collection of relevant ideas, attitudes, opinions and beliefs surrounding a topic, resulting from a variety of sources.

Confounder
A participant from the Q-sort who loads on multiple factors significantly.

Distinguishing aspect
A distinguishing aspect is an aspect that scores significantly different within this group than in all other groups.

Economically Most Advantageous Tender (EMAT)
One of two systems, which are allowed for tender selection (the other being lowest price). EMAT enables tender evaluation on the basis of the quality of the tender offer as well as the price. The quality is scored against a set of award criteria identified for each tender.

Factor
A viewpoint that can be considered as part of the same group. This results in one perspective, participants that have similar Qsorts.

Non-loader
A participant from the Q-methodology who does not load significantly on any factor.

Pre-Qualification Questionnaire (PQQ)
A PQQ enables a contracting authority to evaluate the suitability of potential suppliers in relation to their technical knowledge and experience, capability and financial and economic standing. PQs are used in the restricted procedure, negotiated procedure and competitive dialogue procedure as a means of selecting the bidder to go forward to the next stage of the procurement process.

Q-sort
The foundation of the Q-methodology: the arrangement of the aspects by participants according to the conditions of the research. The completed Qsorts reflects the subjective viewpoints/ perspective of the participant.
**Road tunnel**

Road tunnels as defined by the American Association of State Highway and Transportation Officials (AASHTO) Technical Committee for Tunnels (T-20), are enclosed roadways with vehicle access that is restricted to portals regardless of type of the structure or method of construction. The committee further defines road tunnels not to include enclosed roadway created by highway bridges, railroad bridges or other bridges.

**Selection criteria**

Criteria used at the PQQ stage to select the bidders that are to proceed to the next stage. Selection criteria should only relate to technical and professional capability and financial and economic standing and certain grounds for disqualification.

**Scoring methodology**

The basis on which bids are to be scored against the selection criteria or award criteria.

**Tender**

An official written offer to an invitation that contains a cost proposal to perform the works, services or supplies required, and is provided in response to a tendering exercise. This normally involves the submission of the offer in a sealed envelope to a specified address by a specified time and date.

**Transparency**

Being clear with potential suppliers as to what is planned and the steps that will be and have been taken in relation to a procurement process, and performing that procurement process as described in the communications with potential suppliers.

**Z-scores**

Z-scores are a measure for how far an aspect lies from the middle of the distribution (Webler et al., 2009)

All glossary terms regarding procurement are directly retrieved from the website of the Procurement Portal by Mills & Reeve LLP [www.procurementportal.com/glossary](http://www.procurementportal.com/glossary)
Appendix B : Operationalization of EMAT aspects

In this chapter the conditions for the development of sustainability aspects are identified. In order to create a set of workable EMAT aspects, and therewith the EMAT award criterion for sustainability, the final list of aspects needs to be judged on the basis of these conditions. The condition that will be identified in this chapter will function as a filter, which can be used for the selection and formulation of the final aspects. In the chapter on tests the aspects will be tested on the conditions.

B.1. Conditions from the legal framework

Mostly clients of tunnel construction projects are governmental parties. For these clients it is not possible to design the process and aspects exactly the way they want it, they have to comply with the national public rules. Furthermore, public authorities of the European Union (EU) and member states are subjected to European legislation. As mentioned in chapter 3, if the work to be procured exceeds a certain threshold value, the authorities are obliged to follow the European rules. The European law provides a framework for the design of laws, planning and policies. On the basis of the European procurement regulation it is mandatory for member states to apply the EMAT procurement process.

The Dutch procurement law covers the European rules and in some cases the Dutch rules are even stricter than the European rules. The Procurementlaw 2012 (aanbestedingswet, 2012) is a national law, which covers the Dutch implementation of the European guidelines for procurement (Pianoo, 2014a). Since the Dutch procurement law has been derived from the European law, contracting authorities should always comply with the basic principles. These basic principles are at the same time the first conditions;

- **Proportionality**: ‘requirements for the supplier and in the specification must have an obvious link with and be proportionate in relation to the subject matter of the contract. The requirements imposed must be both appropriate and necessary to achieve the aim of the public procurement’ (Konkurrensverket, 2014).
- **Transparancy**: ‘being clear with potential suppliers as to what is planned and the steps that will be and have been taken in relation to a procurement process, and performing that procurement process as described in the communications with potential suppliers’ (Procurementportal, 2014).
- **Non-discrimination**: ‘it is prohibited to discriminate suppliers, directly or indirectly, on grounds of nationality. Even if the contracting authority does not expect any foreign tenders, it may not, for example, give preference to a local company’ (konkurrensverket, 2014).

On top of these basic principles, additional conditions are created that are necessary conditions to come to the EMAT aspects that are workable for the purpose of the development of a sustainable roadtunnel. The following conditions will ensure the EMAT award criteria characteristics will be reflected in the aspects.

B.2. Conditions from EMAT award criteria characteristics

In order to make the EMAT mechanism work the client that develops the aspects should ask themself the following questions; (Rijkswaterstaat, 2014)

- Do these aspects lead to the creation of extra value?
- Are the aspects easy to understand for all applicants?
- Do these aspects lead to competition between the applicants?
- Is there differentiation in quality possible on the different aspects?
- Do the aspects stimulate parties to devise innovative and sustainable solutions?
In order to make sure that all these questions will be covered, the following conditions are developed where the EMAT aspects need to comply with. In the next sections each condition will be explained shortly.

10.3.1. B.2.1. Distinctiveness

EMAT will be applied to put emphasize on quality. The project delivery organization will select on a combination of price and quality. In order to make an impact with the aspects, they need to focus on aspects that really can make an impact on the quality of the project so that extra value will be delivered. The aspects should lead to distinctiveness between the parties in such a way that there will be different designs with different scores on the aspects. The designs should all fulfill the basic requirements but they should differ enough to make a choice (Sewbalak, 2014). In an interview with a legal expert it was confirmed and emphasized that enough difference and thus distinctiveness is of major importance.

It is often the case that the aspects are formulated in such a way that the tenderers have more or less the same score on the aspects. An interviewed legal expert told that if a score of 0 to 10 is possible, mostly scores will be between 7 and 8, and this is not distinctive enough. If this is the case the EMAT mechanism does not work and price will be dominant again. To avoid this distinctiveness should be taken seriously and the client should think ahead in what way the market might score on the defined aspects and if a wider range in scores is achievable.

There should be a clear distinction in quality offered by the different parties. If this will not be the case and no distinction can be expected on the created aspects than there are two options. Either this aspect should be adopted into the specification and it should be prescribed to the tenderers or it should not be adopted in the EMAT criterion as such because the EMAT mechanism would not work.

10.3.2. B.2.2. Functional specification

By using the EMAT award mechanism the client hopes to stimulate innovation and creativity in the market. The market needs to become excited about the criteria and see opportunities to score on the different aspect by devising innovative and sustainable solutions. To achieve this within the formulation of the EMAT aspects some space and design freedom is needed. Freedom of design means specification of the functionality without coming up with concrete solutions. For example the client could ask for “A connection between A and B instead of a specifying exactly that they want to have a bridge and specify how it should look like.”

To create room for creativity and innovation, functional specification should be used as much as possible and where possible. However, complete freedom and openness of an aspect will not work because then it is not possible to unambiguously compare and judge the different tenderers anymore. Also leaving it open creates extra risks and clients can only bare a certain amount of risk. For the condition ‘functional specification’ a trade-off need to be made between design freedom and specification. In other words: in the output specifications enough freedom of design should be left open for innovative and sustainable alternatives.

10.3.3. B.2.3. Impact on sustainability

To achieve the greatest positive impact towards sustainable development the client should ask itself and subsequently determine what they find important in their project and where are the biggest chances in terms of sustainability in this project area. Where within the project scope is room for sustainable development? The ultimate goal is that tenderers will add value on these aspects that are of real value to the client and have the biggest positive impact on sustainability. Therefore the choice of aspects should depend on the impact that they might have on the project success and thus the greatest impact for sustainable development. This will partly be the same for every tunnel construction project. But also partly it will depend on
the goals of the organization and the specific project surroundings. The client should focus on these criteria that make the chances for the most sustainable solution as large as possible (PIANOo, 2014c).

To take sustainability seriously into account in the weighing of the criteria the wishes towards sustainability should be clearly defined in the output specifications. There will be a better score and more appreciation for these aspects where there is the greatest sustainability benefit.

10.3.4. B.2.4. Number of criteria

In the context of ‘You can only spend each dollar once’ it is important that the tenderer makes a wise choice on which aspects he/she will spend the money. To achieve the greatest environmental gain, it is important that the criteria will have a major impact towards sustainable development as mentioned in the previous section. Therefore it is important the choice of aspects should be limited to a few criteria with a big impact. 50 cents of the dollar could be spent on two criteria or 10 cents on ten different criteria. To have enough weight and distinctive power for each separate aspect is important to create a limited set of aspects (PIANOo, 2014c). The tenderer can better focus on a few items with real impact than to achieve small steps goals on ten aspects. What also could happen is that there are ten aspects and one party focuses on three of them and the other on three others it is not comparable. That way they cannot make big investments for innovation because the spending is too fragmented. Regarding distinctiveness it is also important that the amount of criteria will not be too big. If there are only a few aspects the tenderers know what is expected from them and where to focus on and they could make a difference. From experience Sewbalak shared that three aspects is perfect, and a maximum of five can be workable. The bigger the amount of aspects the less value per aspect.

Another reason why it is important to keep the aspects limited is the transactional costs. All parties can receive a limited amount of compensation. If they need to do research and development on too many aspects they might not be able to develop anything new and all parties will come with the same ideas. Or they do not see financial benefits and they might decide to not invest on sustainability but only on the other EMAT criteria. To conclude there are many reasons why the amount of criteria should be limited to a maximum of five aspects.

B.3. Conditions for operationalization and assessment

To come to a good assessment it is important that all tenderers know how they will be assessed. What is expected from them? Also the client should think ahead how the will score the different tenders. Will it be done qualitatively or quantitatively? Will the judgement be based on the organization or the project? What is the time frame of the assessment and how will it be measured? All aspects need to be operationalized. A broader description on this topic will be given in the next section.

10.3.5. B.3.1. Quantitative versus Qualitative

The aspects can be measured quantitatively, but also qualitatively. On the one hand quantitative criteria are preferred because they are objective and easier to measure and compare. On the other hand, qualitative criteria are preferred since the freedom of design space is needed to devise innovative and stimulating solutions and no these will probably not be enough output specific (Verheijen, 2010). Furthermore quantifying of aspects cost much time especially regarding major construction projects such as tunnels. For qualitative assessment is less specific and less time and money consuming. Quantitative is nice because it is unambiguous and prevents discussion. But it is not an easy project; the construction of the tunnel is too complex (Schone, 2014) for quantitative judgement only. Therefore a combination of both quantitative as qualitative aspects will be needed.
10.3.6. B.3.2. Tender versus tenderer

During the selection phase the candidate will be judged on the organization itself. During the dialogue the selection will be based on as well the organization as the tender project proposal. It might be the case that the organizational goals on sustainability, stated in the corporate social responsibility (CSR) policy, are not distinctive anymore since most large organizations, which could do a tunnel project, have similar developments. Also this project is so big and complex that only judging on the party and trust it will be sustainable is not enough. The environmental impact of the project is more important. Both the tender (project) as tenderer (organization) will be judged, however the tender (project design) will weigh heavier since the selection phase has already been passed.

10.3.7. B.3.3. Life cycle approach

Regarding sustainability it is smart to assess products based on life cycle analyses. When tenders are, for instance, judged on the total cost of ownership (TCO) it means that a financial trade off will be made on the total life cycle of a product. This means that not only initial capital cost but also maintenance cost and asset replacement cost will be taken into account.

10.3.8. B.3.4. SMART

It is important that the aspects will be formulated in clear way so that they are easy to understand for all applicants. If the aspects are clearly formulated then the assessment on the aspects is possible. In 1981 Doran discussed in a paper the importance of developing objectives in an unambiguous and clear way; this is when the S.M.A.R.T. principle was developed. Each letter of the word SMART refers to a condition, which the aspects need to fulfill. Since the development of the principle, SMART has been used in many ways to come to Smart, Measurable, Achievable, Relevant and Time-related objectives. There are many alternatives for the definition of each letter possible, the definitions chosen in this case are the result of discussions with two lawyers specialized in procurement.

- **Specific**; the more specific the aspects will be formulated, the clearer the wishes of the client are to the candidates. Ambiguity should be avoided because the candidates should understand clearly on which aspects and how they can score.
- **Measurable**; it should be clear how the different score on an aspect can be measured and compared. This is important for the client in order to be able to score the different solutions and see which one has the greatest impact. But this is also important for the applicants – they need to know where the solution will be judged upon so that they know where to focus on in finding a solution.
- **Achievable**; the selected aspects should be achievable. However here the word ambitious is also suitable. Since climate goals need to be reached. Is the solution ambitious towards climate goals, but is it achievable as well?
- **Relevant**; are the solutions relevant to the goals of the organization, the policy and the project environment?
- **Time-related**; When will the solutions be executed within the project lifetime?

However the aim is to make the aspects as ‘SMART’ as possible. However regarding sustainability it is not always possible to make everything measurable or it will cost loads of time and money. Especially if there are multiple subscribers left it will be too costly. Therefore for some aspects a qualitative judgement needs to satisfying.
B.4. Conclusion on conditions

The Dutch law and European principles are the basic conditions that the aspects should fulfill these are:

- Proportionality
- Transparency
- Non-discrimination

Besides that there are some characteristics for EMAT mechnism and which are necessary to make this procurement system work. These conditions are:

- Functional specification
- Distinctiveness
- Impact on sustainability
- Number of criteria

Additionally all criteria need to be assessed properly.

- Quantitative versus qualitative
- Tenderer versus tender
- SMART
- Life cycle approach

On the basis of these conditions the inventory of possible aspects can be judged. This way the aspects can be judged on their effect and if they are useful for the procurement process. The aspects that fulfill these criteria are possible sustainability aspects for tunnel construction projects.
# Appendix C: Inventory and framework with sustainability aspects

<table>
<thead>
<tr>
<th>No.</th>
<th>ID</th>
<th>Category</th>
<th>Description</th>
<th>Occurrence</th>
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<td>1</td>
<td>Added Value</td>
<td>Flexibility The combination of multiple functions within the tunnel</td>
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<tr>
<td>2</td>
<td>2.1</td>
<td>Reality</td>
<td>The future value of the tunnel construction, flexibility in use, and sustainability aspects</td>
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</tr>
<tr>
<td>3</td>
<td>2.2</td>
<td>Multifunctionality</td>
<td>The combination of multiple functions within the tunnel</td>
<td>6</td>
</tr>
<tr>
<td>4</td>
<td>2.3</td>
<td>Additivity and interconnectivity</td>
<td>The quality of the tunnel, this is about aesthetics and usability of the tunnel</td>
<td>6</td>
</tr>
<tr>
<td>5</td>
<td>2.3</td>
<td>Landmark</td>
<td>The quality of information and learning with the environment</td>
<td>6</td>
</tr>
<tr>
<td>6</td>
<td>2.3</td>
<td>Knowledge Retention</td>
<td>The quality of information and learning with the environment</td>
<td>6</td>
</tr>
<tr>
<td>7</td>
<td>2.3</td>
<td>Community impact</td>
<td>The quality of information and learning with the environment</td>
<td>6</td>
</tr>
<tr>
<td>8</td>
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<td>Added Value</td>
<td>Flexibility and adaptivity</td>
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<td>13</td>
<td>2.3</td>
<td>Added Value</td>
<td>Community impact</td>
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</tr>
</tbody>
</table>

### Filtered aspects

- Added value of flexibility and adaptivity
- Added value of multifunctionality
- Added value of adaptivity and extendibility
- Added value of Landmark
- Added value of Knowledge Retention
- Added value of Community impact

### Comments

- Added value of flexibility and adaptivity: merge with flexibility
- Added value of multifunctionality: merge with flexibility
- Added value of adaptivity and extendibility: merge with flexibility
- Added value of Landmark: only mentioned once
- Added value of Knowledge Retention: only mentioned once
- Added value of Community impact: only mentioned once

### Additional comments

- Air Quality: looking at the three substances as a part of general aspects air quality
- Energy: this is too specific. A mean is not an aspect
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<td>floods (tunnel as flood control measure), droughts, heat waves, storms, rain extreme</td>
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<td>Origin of the materials</td>
<td>where does the material come from/what where the production circumstances</td>
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<td>Future oriented development, anticipating traffic growth, however not for too far, room for adaption</td>
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<td>use of excess soil / recycling of the soil / soil-balance</td>
<td>Use of high quality recycling / reuse of soil (for example by stabilization of the ground) / closing the soil cycle</td>
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<td>Pollution caused by construction activity and use of the tunnel</td>
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<td>Flora &amp; Fauna (ecology and biodiversity)</td>
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<td>27 habitat restoration</td>
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<td>Habitat restoration flora</td>
<td>Destruction and deterioration of natural habitat, caused by the tunnel construction. Restore and protect natural habitat beyond regulatory requirements. And recover environmental area (if road is replaced underground)</td>
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<td>Habitat restoration fauna</td>
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<td>Amount of day and sunlight in the tunnel</td>
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<td>Training of employees involved in the project on sustainability awareness</td>
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<td>related to criteria in materials (where produced and under which circumstances)</td>
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**Filtered aspects**

- 18 healthy project environment, reducing use of toxics
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- 18 healthy project environment, reducing use of toxics
- 18 healthy project environment, reducing use of toxics
- 18 healthy project environment, reducing use of toxics
- 28 Environmental monitoring and management system
- 28 Environmental monitoring and management system
- 28 Environmental monitoring and management system
- 28 Environmental monitoring and management system
- 28 Environmental monitoring and management system
- 29 Holistic approach
- 30 minimizing construction waste
- 30 minimizing construction waste
- 30 minimizing construction waste
- 30 minimizing construction waste
- 31 social fairness
- 4 local stakeholder involvement and 32 social return
- 32 social return
- 31 social fairness
- 31 social fairness
- 31 social fairness
- 32 social return

**Notes**

- Not enough impact in tunnels
- Can be merged with management, but good measurable
- Related to for example smart usage of machines (het nieuwe draaien), however it is too specific; it is already a measure / mean to achieve the higher goal
- Can be merged in environmental management system and made less specific on energy, that is already represented in energy aspects
- (Het nieuwe draaien)
## Pre-selection step between Inventory and Initial framework

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<td>air quality (fine dust, nano fine particles and Nox)</td>
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<td>use of fossil fuels</td>
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<td>energy usage operational phase</td>
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<td>conscious selection of materials with consideration for the global environment</td>
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<td>18</td>
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<td>space for unexpected solutions on sustainability/innovation</td>
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<tr>
<td>54</td>
<td>Nature / natural environment</td>
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## Tunnel Visions on Sustainability

### Context-project documents
- URBACT project The Hague (2007)

### Building Assessment Tools
- CASBEE (2013)
- LEED-neighborhood (2013)
- GPR-Urbanism (2011)
- Greenroads
- Greenlites
- Envision
- BE2STINSHWYS
- ISLAST
- INVEST
- 1-Vlaketunnel
- 2-Hindheadtunnel
- 3-M30-Madrid-Calle-30-project
- 4-Smart-Tunnel
- 5-Solar-Tunnel-(HSL-Antwerpen)
- 6-Laerdal-Tunnel
- 7-Tunnel-van-de-Toekomst
- 8-Fehmarnbelt-Tunnel-
- 9-Gotthard
- 10-A2-Maastricht
- 11-Crossrail
- 12-Bunnik-S-Groene-tunnel
- 13-Sluiskiltunnel

### Infrastructure Assessment Tools
- CEEQUAL
- Life-CYCLE
- Cap-IT
- DuurzaamGWW

### Experts
- SUSTAIN
- EIA-report-Rotterdamsebaan-by-Anteagroup-(2013)
- Report-Duurzaam-gebruik-ondergrond-TCB-(2012)
- Preliminary-draft-Rotterdamsebaan-by-Movares-(2013)
- Duarte,-Cooke-(2013)
- Derek-Penrice-and-Bradford-Townsend-(2010)
- Expert-Spatial-Planning-(2014)
- Expert-Underground-Construction-(2014)
- Expert-Geosciences-(2014)
- Sustainable-Energy-Expert-/-Climate-activist-(2014)
- Expert-Systems-Engineering-Infrastructure-(2014)
- Expert-Environmental-Technology-&-Design-(2014)

### Reference tunnel projects
- Framework-Expertteam-Rotterdamsebaan-(2014)
- Others

### Occurrence
- 1
- 2
- 3
- 4
- 5
- 6
- 7
- 8
- 9
- 10
### Content project documents

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### Building Assessment Tools

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### Reference tunnel projects

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### Assessment Tools

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### Others

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</tr>
</tbody>
</table>

### Context - project documents

1. Framework Expertteam Rotterdamsebaan (2014)
4. Preliminary draft Rotterdamsebaan by Mott MacDonald (2013)
5. Duarte, Cooke (2013)
12. BREEAM (2012)
13. CASBEE (2013)
14. LEED-neighborhood (2013)
15. Greenroads
16. Greenlites
17. Envision
18. B2ENORSN
19. ISLAST
20. INVEST
21. BE2STSINSHWYS
22. 1-Vlaketunnel
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30. 9-Gotthard
31. 10-A2-Maastricht
32. 11-Crossrail
33. 12-Bunnik-S-Groene-tunnel
34. 13-Sluiskiltunnel
35. CEEQUAL
36. Life CYCLE
37. Cap IT
38. Waste Management Framework
42. Report Duurzaam gebruik ondergrond TCB (2012)
44. Report Duurzaam gebruik ondergrond TCB (2012)
Appendix D: Different tunnel types

Considering different types of tunnels there exist three main types of tunnels. The reason why this is mentioned in this research is because the different construction methods of the tunnels have different environmental footprints. A distinction can be made between three different tunnel families: the immersed tunnel, the bored tunnel and the cut-and-cover tunnel method. We will shortly describe the different tunnel types, the areas of use, the general advantages and disadvantages and the chances and impossibilities regarding sustainability and this specific tunnel type (van der Woude, 2009; Bosch, 2014).

“Selection of the type of tunnel is an iterative process taking into account many factors, including depth of tunnel, number of traffic lanes, type of ground traversed, and available construction methodologies.” (FHWA, 2013)

Sustainability should be an integrated aspect taken into account by selecting the type of tunnel.

**Immersed tunnels**
- **Use:** Primarily used for crossing of rivers and canals of limited depth. Lot of immersed tunnels has been constructed because of Delta area. Lot of expertise in the Netherlands.
- **Advantages,** compared to a bored tunnel; shorter ramps and shallower
- **Disadvantage** (compared to a bored tunnel).
  - Hindrance during construction caused by dredging,
  - transport of elements, immersing
  - construction of the ramps are adjacent to immersed tunnel (bored tunnels more freedom in alignment)
  - construction of a dock

**Bored tunnels**
- **Use:** primarily used for river canals, crossing deep waterways and any vulnerable object, such as historic city centres (Amsterdam), residential areas, congested cities and long tunnels under mountains.
- **Advantages:**
  - Little hindrance during construction
  - Shafts can be located on optimal location
- **Disadvantage:** compared with an immersed tunnel; deeper launching and reception shaft of TBM. Longer
- **Old method, constructing in soft soil relatively new**
- **TBM: big machine used cost lot of power**
- **Sustainability advantage:** no damage on the surface, little hindrance for surroundings,

(Slurry shield versus EPB)

**Cut and cover tunnels**
- **Use:** shallow tunnels in urban areas with moderate surface constraints
- **Disadvantage** open building pit, however duration of hindrace is limited

There are also different applications; landtunnel, city tunnel, water tunnel etc. however this distinction is out of the scope of this research.

These kinds of choices are made in different phases. The choice of tunnel has been made before the procurement starts.
Appendix E: Used Q-questionnaire research model

In this appendix the used Q-questionnaire model is depicted. The model existed of 6 different steps with an instruction page and accompanied instructions in the email to the participants. The Excel model will be displayed on the next pages, starting with the introduction on tab 1 and ending with the closing page on tab 7.

Tab 1 Instruction
Tab 2: step 1 rough sorting process

Lees alstublieft de duurzaamheidsaspecten (en bijbehorende definities) door en geef aan of u deze belangrijk (B), neutraal (N) of minder belangrijk (M) vindt bij de bouw van een duurzame weg tunnel. (Duur van deze stap: +/- 5 minuten)

Deze stap betreft een grove sortering van de verschillende aspecten, die u zal helpen bij de uiteindelijke rangschikking. Een aantal duurzaamheidsaspecten zijn u misschien relatief onbekend en daarom zijn die voorzien van een voorbeeld.

<table>
<thead>
<tr>
<th>No.</th>
<th>Aspect</th>
<th>Definicie</th>
<th>Voorkomt</th>
<th>B/N/M</th>
</tr>
</thead>
</table>
| 1   | Functionele flexibiliteit | Het vermogen van de tunnel om als zodanig te fungeren in de infrastructura na wijzigingen in | nieuwbouw | |}
| 2   | Multidisciplinaire zorg | het multidisciplinaire karakter van het | | |}
| 3   | Duurzame zichtbaarheid | De zichtbaarheid van de tunnel voor andere | | |}
| 4   | Klimaatbestendigheid | De uitwerking van de impact op de lokale | | |}
| 5   | Ruimte bestaat moeheid | Moeheid is een van de onderliggende | | |}
| 6   | Duurzaam bouwen | Het bouwen van de tunnel met als doel om | | |}
| 7   | Gebouwde materialen en | door leiders in de bouwsector en het gebruik | | |}
| 8   | Energy eten en | Biologische en biologische stoffen en | | |}
| 9   | Kringloop | producten die gemaakt zijn van enige | | |}
| 10  | Ongunstig voor natuur | Inbreken op de natuur | | |}
| 11  | Duurzaam energiegenos | Het gebruik van duurzaam energie | | |}
| 12  | Energiegebruik | Gebouwde energie | | |}
| 13  | CEZ uitstoot | De uitstoot van de CEZ activiteiten met | | |}
| 14  | Toonzaamheid | Het toonzaamheden van de tunnel | | |}
| 15  | Functionele (grond)waterstroom | Het standplaats van de grondwaterstroom en | | |}
| 16  | Alers van de grond | Het alers van de grond | | |}
| 17  | Bodemkwaliteit | Het bepalen van de bodemkwaliteit | | |}
| 18  | Bodemwater | De waterkwaliteit van de bodemwater | | |}
| 19  | Biodiversiteit (Bos en | De biodiversiteit en ecologische | | |}
| 20  | Natuurbescherming | Het bescherming van de natuur | | |}
| 21  | Lichtgezondheid | Het lichtgezondheid van de tunnel | | |}

Dit is een voorbeeld van de mogelijkheden van de tunnel.
Tab 3: Appointing the extreme aspects

We zien graag dat u aangeeft welke twee duurzaamheidsaspecten u het belangrijkst vindt, en welke twee het minst belangrijk zijn voor een duurzame wegtunnel. U kunt dit aangeven door middel van het plaatsen van een X en een Y. (Duur van deze stap: +/- 2 minuten)

![Image of a table and instructions in Dutch]

---

**Tab 3: Appointing the extreme aspects**

We zien graag dat u aangeeft welke twee duurzaamheidsaspecten u het belangrijkst vindt, en welke twee het minst belangrijk zijn voor een duurzame wegtunnel. U kunt dit aangeven door middel van het plaatsen van een X en een Y. (Duur van deze stap: +/- 2 minuten)
Tab 4 explanation on the extremes

Graag een toelichting waarom deze duurzaamheidsaspecten voor u het meest en minst van belang zijn. (Duur van deze stap:+/- 5 minuten)
Tab 5 Q-sorting

Sleep alstublieft de blokjes waarin de duurzaamheidsaspecten zich bevinden van onder in het scherm naar het figuur boven in het scherm. (Duur van deze stap: +/-15 minuten)

I. De blokjes zijn verdeeld over een de horizontale en verticale as. De horizontale as geeft een waarde weer (van -4 tot +4) op schaal van belangrijkheid. Op de verticale as worden alle blokjes als even belangrijk beschouwd.

II. Het kan zijn dat u alle 35 gepresenteerde aspecten belangrijk vindt. Toch is het van belang dat u een keuze maakt. Deze afweging en keuze is karakteristiek voor de Q-methodologie.

III. Voor de analyse van de data en het afleiden van uw perspectief is het enorm van belang dat u het volledige formulier invult!
Tab 6 Additional questions

Vervolgens vragen wij u een korte vragenlijst en uw personalia in te vullen. (Duur van deze stap +/- 3 minuten)
Deze vragenlijst is van belang voor het interpreteren van de rangschikkingen en het afleiden van de verschillende perspectieven op duurzame wgtunnels. Uw persoonlijke gegevens zullen natuurlijk anoniem gehouden worden bij de verwerking van het onderzoek.

![Image of a questionnaire form]

**Hoeft u nog iets gemist?**
**Opleiding**
**Ervaring met duurzaamheid in projecten**
**Ervaring met infrastructuur, ondergrondse, of tunnelprojecten**
**Huidige functie en/of expertise**
Tab 7 Thank you and closing

U heeft het onderzoek voltooid? Wij verzoeken u om uw resultaten op te slaan in het Excelbestand op uw computer en mail het bestand naar: d.j.gijzel@student.tudelft.nl

Ontzettend bedankt voor uw tijd en deelname aan dit onderzoek!

Alle aspecten zijn gerangschikt en de vragen zijn beantwoord!

Stap 1: Type een B,N of M in achter elk aspect
Stap 2: Type per kolom een X en een Y in
Stap 3: Licht uw keuzes toe
Stap 4: Sleu de blokjes in de figuur naar mate van hoe belangrijk u het aspect vindt
Stap 5: Vul de vragenlijst en uw personalia in
Stap 6: Sla uw resultaten op en mail ze naar d.j.gijzel@student.tudelft.nl
Appendix F: Output PQ method

Correlation matrix between sorts
Depicted below is the correlation matrix between all Q sorts from all participants. These results are extracted from PQ method. 100 means the participants have the exact same Q-sort. -100 means that they are totally opposites.

Unrotated factor matrix
PQ-method automatically derived 8 with an eigenvalue greater than 1. All factors with an eigenvalue above 1 can be considered as a potential factor to arrive at perspectives. However as explained in chapter 6, rotation was necessary to arrive at 4 clear perspectives (factors).
Factor scores
In the table below all scores per aspect resulting from different factors are shown. This data is derived from the output of PQmethod.

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Appendix G : Interview inventory of sustainability aspects

Algemene informatie
Fase onderzoek: data verzameling, het opstellen van een long list van duurzaamheidscriteria
Datum:
Locatie:

Interview

<table>
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Introductie
- toelichten in welk kader het interview plaatsvindt
- mijn afstudeeronderzoek toelichten, mijn rol bij de Rotterdamsebaan
- toelichten waarom ik graag deze geïnterviewde wou interviewen
- vragen om toestemming gesprek op te nemen
- aangeven dat ik een verslag schrijf en dat aan geïnterviewde stuurt ter verificatie

Doel van interviews eerste fase
➔ een inventarisatie van duurzaamheidscriteria maken
➔ in de eerste fase mensen interviewen met iets afstand van de praktijk
➔ voorbeelden verzamelen van projecten/cases waar duurzaamheidscriteria toegepast zijn
➔ voorbeelden verzamelen hoe duurzaamheid beoordeeld kan worden
➔ feedback ontvangen op reeds opgestelde lijst

Specifiek doel voor dit interview (eerste)
➔ belangrijkste criteria volgens de geïnterviewde (vanuit zijn expertise)
➔ concrete, toegepaste duurzaamheidscriteria van de geïnterviewde
➔ ervaringen met duurzaamheid bij ....

Vragen
Duurzame tunnel

1. Wat is volgens u een duurzame tunnel?
2. Welke aspecten zijn vanuit uw discipline en expertise heel belangrijk bij het ontwerpen, realiseren en onderhouden (t/m end of lifetime) van een duurzame tunnel?
3. En vanuit een breder perspectief; wat zijn de belangrijkste aspecten voor het ontwerpen, realiseren en onderhouden van een duurzame tunnel?

Duurzaamheidscriteria algemeen

4. Met welke duurzaamheidscriteria heeft u wel eens gewerkt?
5. Hebben jullie bij …. eigen ontwikkelde duurzaamheidscriteria?
   (als 4 positief was beantwoord, dus er al wel eens met duurzaamheidscriteria gewerkt is)
Toepassing

6. Hoe zijn deze criteria opgenomen/toegepast in projecten?
7. Wat waren de motivaties achter het gebruik van deze criteria? *Kwam dit vanuit jullie bedrijf / de opdrachtgever / de aannemer...?*

Operationalisering

8. Hoe vond de beoordeling / operationalisering van deze criteria plaats?
9. Hebben jullie de tot nu toe genoemde criteria ook meetbaar en vergelijkbaar gemaakt?
10. Heeft u gebruik gemaakt van weegfactoren?
    a. Zoja, welke criteria wegen beduidend zwaarder dan anderen?
    b. Zonee, waarom niet?
11. Was duurzaamheid in de eisen specificatie meegenomen? En wat was het niveau? En in relatie tot EMVI?

Labels

12. Heeft u wel eens gebruikt gemaakt van duurzaamheidslabels? Zo ja, welke?
13. Wat zijn de voor en nadelen?
14. Welke aspecten zouden volgens u bruikbaar kunnen zijn voor tunnels?

Long list

Dit is mijn initiële lijst van mogelijke EMVI duurzaamheidscriteria die toegepast zouden kunnen worden in tunnel projecten. (A4 met mijn lijst tot nu toe laten zien)

15. Wat is uw eerste reactie......
    a. Mist u bepaalde aspecten?
    b. Zijn er bepaalde aspecten opgenomen die niet relevant zijn?
    c. Zou u bepaalde aspecten anders operationaliseren?

Extra

Hoe denkt u dat duurzaamheid in andere criteria zoals selectiecriteria, minimum voorschriften of in het contract meegenomen zou kunnen/moeten worden?

Take-aways

Heeft u verder nog vragen, opmerkingen of tips voor mijn onderzoek?

Bedanken!

En het interview protocol (dat ik van te voren over de mail heb opgestuurd) nog een keer doornemen.

Next steps:
- ik mail het verslag binnen 24uur toe
- of de geïnterviewde binnen 1 week een akkoord of opmerkingen zou kunnen terugmailen
- ik breng u op de hoogte van de resultaten van het onderzoek