University of Twente
MASTER THESIS

Sustainable Concrete in the construction industry in the Netherlands

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Abstract

The construction sector in the Netherlands plays a significant role in the country's sustainability goals, but it is also a major contributor to environmental impact. Concrete, the primary building material, contributes to CO_2 emissions, waste generation, and raw material consumption. The industry needs to adopt more sustainable practices to achieve the ambitious sustainability targets the Dutch government sets. This research aims to propose policies that can accelerate the transition towards a more sustainable building industry, with a focus on sustainable concrete.

The study begins by assessing the Dutch construction industry's sustainable concrete adoption level. It then identifies the drivers and barriers that influence construction companies' decision-making processes regarding sustainable concrete. The Transition Innovation System (TIS) framework is employed to analyze the interaction between these drivers and barriers. The research also seeks to answer how the transition to a more sustainable building industry can be accelerated.

Through two interviews, ten surveys with experts, and using the TIS framework, valuable insights into the drivers and barriers affecting the implementation of sustainable concrete in the Netherlands are gained. The TIS framework, which encompasses actors, networks, and institutions, provides a comprehensive approach to studying technological innovation and helps identify strategies for promoting the adoption of sustainable concrete.

The research findings reveal the need for increased funding for research and development in sustainable concrete technologies. Clear regulations and standards specific to sustainable concrete should be established to guide industry stakeholders. Collaboration and knowledge-sharing platforms should be expanded to foster innovation and accelerate the development of sustainable concrete technologies. Efforts should also be made to enhance market accessibility and availability of sustainable concrete materials.

Awareness campaigns and educational initiatives are recommended to address the lack of knowledge and awareness surrounding sustainable concrete. Financial incentives can incentivize the adoption of sustainable concrete practices. Additionally, robust testing and validation processes are essential to ensure the reliability and long-term performance of sustainable concrete materials.

Implementing these recommendations will help overcome the identified barriers and enhance the drivers for sustainable concrete adoption, contributing to a more sustainable and resilient construction industry in the Netherlands. The transition to sustainable concrete technologies will lead to reduced environmental impact, improved resource efficiency, and a more sustainable built environment.

Keywords: Sustainability goals, Concrete industry, CO_2 emissions, Sustainable practices, Transition Innovation System (TIS) framework, Drivers and barriers, Sustainable concrete technologies

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2. CHAPTER 1: INTRODUCTION

2.1 Background

Climate change is becoming increasingly evident across the world, and the expected consequences will result in even bigger and more widespread transformations in the form of extreme weather events, flooding, rising sea levels, and rising temperatures (Hesselink & Chappin, 2019). Furthermore, various industries have played a role in exacerbating this issue, and the construction sector is recognized as one of the primary contributors (Hesselink & Chappin, 2019). There are various ways that industry influences climate change. The use of materials is one of the most important methods. A significant quantity of CO2 is released into the environment during the manufacture of the materials used in the building industry. For instance, 8% of the world's carbon dioxide emissions result from cement production (Marey et al., 2022).

Moreover, the energy usage of the building industry contributes to climate change. Building environments need energy to be heated, cooled, and powered, and this type of energy use significantly contributes to the emissions of green gases that accelerate climate change. Buildings account for 39% of all energy use and 33% of all greenhouse gas emissions (UNEP, 2019; WGBC, 2019).

In addition, the construction industry also generates a significant amount of waste. This waste includes materials such as concrete, wood, and steel that are produced during the construction, demolition, and renovation process. It has a negative impact on the environment, as it needs a huge amount of space in landfills and releases harmful chemicals into the soil and water, and air. This waste often represents 50 % of the total solid waste collected by municipalities (Yeheyis et al., 2013).

Relatedly, it is imperative to implement sustainable construction practices to solve the environmental challenges posed by the construction industry. These practices encompass the use of eco-friendly materials, designing buildings that optimize energy efficiency, and minimizing waste generation. By adopting such measures, we can significantly reduce the adverse effects of the construction industry on climate change (Mavi et al., 2021).

Sustainable building methods must be given top priority in consideration of the construction industry's substantial role in climate change. We are having a reduction in the use of non-renewable resources, greenhouse gas emissions, and waste aids in reducing the sector's ecological footprint (Mavi et al., 2021). A more sustainable future can be created for our world by actively lowering industry's contribution to climate change.

2.2 Problem statement

The Dutch construction sector plays a significant role in achieving the country's sustainability goals, as it accounts for about 50% of Dutch raw material consumption, about 40% of energy consumption, and about 35% of total Dutch CO2 emissions (Nederland et al., 2014). This means that the construction sector is a major contributor to the overall environmental impact of the Netherlands and makes it an important area to focus on when working to achieve the country's sustainability goals.

One of the major materials used in construction is concrete, which has the largest building material flow in the Netherlands (Materiaalstromen in de Bouw En Infra, 2022). However, when structures are demolished, large quantities of concrete are also released as waste, and almost one-fifth of all Dutch waste is concrete. The production process for concrete is also responsible for 3% of Dutch CO_2 emissions and places a large demand on increasingly scarce primary raw materials (Peter of Ghent, 2021).

The Dutch government has set ambitious targets for reducing greenhouse gas emissions and primary raw material usage in the construction sector. The goal is to achieve a 49% reduction in greenhouse gases and a 50% reduction in primary raw material usage by 2030. This will require the industry to adopt new technologies and practices that are more energy-efficient and sustainable. This includes the use of renewable energy sources, energy-efficient building designs, and sustainable materials (Peter of Ghent, 2021).

In addition, the Dutch government has set specific targets for CO_2 reduction and reuse in the concrete sector, including in the Concrete Agreement, aiming to achieve a 100% reduction in CO_2 emissions by 2050 (5 million tons) and a 100% high-quality reuse of released concrete by 2030. This highlights the need for more sustainable practices in the concrete sector and the importance of considering the entire lifecycle of concrete, from sourcing, production, use, and end-of-life(Peter of Ghent, 2021).

Finally, another target is to achieve a fully circular economy and a 95% reduction in CO_2 emissions by 2050 (Peter of Ghent, 2021). This will require the construction sector to adopt circular building practices, such as using recycled materials, designing buildings for disassembly and recycling, and implementing closed-loop systems for materials and energy. By these means the entire lifecycle of buildings and materials should be considered, starting from sourcing, design, construction, use, and maintenance to end-of-life.

However, to achieve these goals, the construction sector will need to collaborate with the government, research institutions, and other stakeholders to develop and implement sustainable technologies and practices. This will require significant investments in research and development, as well as changes in regulations and policies to support the transition to a more sustainable construction sector. Additionally, it is important to raise awareness and educate the industry and the public about the benefits of sustainable building practices and technologies.

2.3 Research objective

The aim of this research is to propose policies that could accelerate the transition towards a more sustainable building industry in the Netherlands. This goal will be accomplished in two steps. Initially, I determine how much sustainable concrete is being used. Following that, I closely examine the reasons that push construction companies to adopt sustainable concrete more and the obstacles that might prevent them from doing so. The analysis of drivers and barriers will be conducted using Transition Innovation System (TIS) functions (Bergek et al., 2008).

The objectives of the research can be summarized as follows:

1. Determine the current level of adoption of sustainable concrete in the construction industry in the Netherlands.
2. Identify the drivers and barriers that influence construction companies to shift towards sustainable concrete.
3. Analyze the interaction between the drivers and barriers using TIS functions and propose policies to accelerate the transition towards a more sustainable building industry.

2.4 Research questions

Main Research Question

"What policy changes are required to overcome the barriers and to enhance the drivers that can accelerate the implementation of sustainable concrete in the Netherlands?"

Sub-Questions

1. What is the current level of adoption of sustainable concrete in the construction industry in the Netherlands in terms of reduction in CO_2 emission percentage?
2. What are the drivers and barriers that affect Dutch construction companies to implement sustainable concrete?
3. Considering TIS functions (drivers and barriers), how to accelerate the transition to a more sustainable building industry?

2.5 Organization of the Thesis

The structure of the thesis is outlined as follows:

The introduction chapter included background, problem statement, research objective, and research questions. Chapter two is dedicated to conducting a thorough literature review and establishing the theoretical framework that formed the foundation for carrying out this research. In chapter three, the research methodology is extensively discussed, encompassing aspects such as the research framework, research strategy, data collection, data analysis, and analytical framework. Moving on to chapter four, the research findings, primarily derived from interviews, are presented. Subsequently, in chapter five, the results are examined, and the main research question is addressed by analyzing the findings alongside relevant primary data. Finally, the last chapter serves as a conclusion to the research, offering recommendations based on the research conducted.

3. CHAPTER 2: LITERATURE REVIEW

3.1 Sustainable construction

Sustainable construction, also known as green building (Kibert, 2016), refers to designing, constructing, renovating, and demolishing buildings in an environmentally and socially responsible way. The goal of sustainable construction is to reduce the environmental impact of buildings and the construction industry, while also promoting human health and well-being (Mavi et al., 2021). Sustainable construction involves the use of sustainable materials, designing buildings to use energy and resources more efficiently, reducing waste and pollution during construction, and incorporating renewable energy sources. It also considers the social impact of construction, such as the health and safety of workers and the impact on local communities (Shen et al., 2010).

Some examples of sustainable construction practices include using recycled materials, especially concrete, using energy-efficient lighting and appliances, incorporating natural ventilation and lighting into building design, using water-efficient fixtures and landscaping, and using renewable energy sources such as solar and wind power (Akadiri et al., 2012; Amaral et al., 2020). Additionally, it aims to create buildings that are not only environmentally and socially responsible but also economically viable and able to meet the needs of the present without compromising the ability of future generations to meet their own needs (Mavi et al., 2021).

Using recycled materials is an important aspect of sustainable construction as it helps to reduce waste and conserve natural resources. Instead of using virgin materials, which require significant amounts of energy and resources to extract and process, recycled materials can be used to reduce the environmental impact of construction (Akadiri et al., 2012). Using recycled materials in construction also helps to divert waste from landfills, which reduces the environmental impact of waste disposal. It also helps to conserve natural resources, as less energy and resources are required to extract and process virgin materials (Akadiri et al., 2012).

In addition to using recycled materials, sustainable construction involves designing buildings to be easily disassembled and materials to be reused or recycled at the end of their useful life(Amaral et al., 2020). This promotes a circular economy, where materials are kept in use for as long as possible, reducing the need for new resources to be extracted and processed. For instance, concrete is one of the most widely used building materials in the world, but it has a significant environmental impact due to the large amounts of energy required to produce it and the emissions generated during production. However, there are several ways in which concrete can be made more sustainable (Javadabadi et al., 2019). One example is the use of recycled aggregates in concrete. Recycled aggregates are made from crushed concrete and other construction and demolition waste, which reduces the amount of waste sent to landfills and conserves natural resources. By using recycled aggregates instead of virgin aggregates, the environmental impact of concrete production can be reduced (Amaral et al., 2020).

3.2 Sustainable Concrete

Sustainable concrete is a type of building material that is designed to reduce the environmental impact of construction activities(Surahyo, 2019). It involves the use of various methods and techniques to minimize the use of natural resources, reduce waste, and decrease greenhouse gas emissions throughout the lifecycle of the concrete (Altarrazi et al., 2022; *Cement and Concrete Sustainability*, 2023).

One approach to achieving sustainable concrete is through the reuse of concrete elements obtained from demolition waste (Küpfer et al., 2023). By recycling and repurposing concrete that would otherwise be sent to landfill, the environmental impact of concrete production is reduced, and valuable resources are conserved(Amaral et al., 2020). The use of recycled aggregates is also an important aspect of sustainable concrete. These secondary material flows are typically made from crushed concrete, masonry, or other waste materials, which are processed to meet the required specifications. By using recycled aggregates, the demand for natural resources, such as gravel and sand, is reduced (Surahyo, 2019).

Another key aspect of sustainable concrete is the development of new types of concrete with less cement (Javadabadi et al., 2019). Cement production is a significant contributor to carbon dioxide emissions, which are a major contributor to climate change. By using alternative materials such as fly ash, slag, and pozzolanic materials, the amount of cement needed in concrete production can be reduced, while still maintaining the desired strength and durability (de Brito & Kurda, 2021a).

Leaner construction is also a key aspect of sustainable concrete. This involves optimizing the design and construction process to reduce waste, improve energy efficiency, and minimize the use of materials (Akadiri et al., 2012). By using prefabricated concrete components, for example, the amount of on-site waste can be reduced, and construction time can be shortened.

Demountable construction is an increasingly important aspect of sustainable concrete. By designing buildings and structures with the ability to be disassembled and reused, the environmental impact of construction activities can be further reduced. This type of concrete also promotes circular economy principles, by enabling materials and components to be reused, rather than discarded (Fayyad & Abdalqader, 2020).

3.3 Barriers and Drivers for sustainable concrete use

To identify the drivers and barriers of sustainable concrete, I conducted a review of relevant academic literature and industry reports and drew on my experience working in the construction industry. I searched academic databases, such as Scopus and Web of Science, using keywords related to sustainable concrete, such as "green concrete," " sustainable concrete," and "Drivers and Barriers." I also searched for reports and policy documents from industry organizations, such as the World Green Building Council and the Cement Sustainability Initiative.

After conducting extensive research, I was able to gather 22 articles and 7 related reports. Upon further review, I determined that 15 articles and 3 reports were particularly useful for gaining a deeper understanding of the topic at hand (Appendix I). Through analyzing this selection of literature, I have been able to identify both barriers and drivers.

3.3.1 Barriers to sustainable concrete use

Nevertheless, even if sustainable concrete has many advantages, there are several barriers that hinder its adoption as a building material, which include:

1. Cost: Concrete consisting of water, cement, and aggregate. Recycling aggregates from demolished structures can reduce the need for new extraction of natural resources, decreasing the environmental impact. New types of cement, such as geopolymer and fly ash cement, have a lower environmental impact compared to traditional Portland cement. In addition, treated wastewater can be used in concrete production, reducing the need for freshwater (Arıoğlu Akan et al., 2017; Javadabadi et al., 2019).

   As a result of using environmentally friendly material, sustainable concrete typically costs more than traditional (Zhao et al., 2020) which can make it a less appealing option for some construction projects.

2. Lack of Awareness: Many individuals are unaware of the advantages of sustainable materials, including sustainable concrete, including its reduced carbon footprint, and environmentally friendly production process (Alsanad, 2015).

3. Limited Availability: Sustainable concrete is still a relatively new product and may not be readily available in all areas. This can make it difficult for builders and contractors to access the materials they need for construction projects (Altarrazi et al., 2022; *Materiaalstromen in de Bouw En Infra*, 2022).

4. Technical Challenges: There can be technical challenges associated with using sustainable concrete, such as ensuring it has the necessary strength and durability for different types of construction projects(Müller et al., 2019).

5. Regulatory Barriers: There may be regulatory barriers that prevent the widespread adoption of sustainable concrete, such as building codes and standards that do not yet recognize sustainable concrete as a suitable building material (Altarrazi et al., 2022).

6. Resistance to Change: Some construction companies and contractors may be resistant to change and prefer to continue using traditional concrete, which they are familiar with and have used for many years (Altarrazi et al., 2022).

7. Perception of Quality: Some people may view sustainable concrete as a lower-quality option compared to traditional concrete, which can make it less appealing for certain types of construction projects(Altarrazi et al., 2022).
8. Access to Financing: Some organizations may not have access to the financing they need to invest in sustainable concrete, which can limit its adoption(de Brito & Kurda, 2021).
9. Resistance from Suppliers: Some concrete suppliers may not be interested in offering sustainable concrete due to the higher costs associated with producing it and the lower demand for the product(Altarrazi et al., 2022).

The nine barriers mentioned can prevent the widespread commercialization of sustainable concrete as a building material. However, efforts to overcome these barriers, such as increasing public awareness, improving the availability of sustainable concrete, and addressing technical and regulatory challenges, can help to promote its use and drive the growth of the sustainable concrete market.

3.3.2 Drivers to sustainable concrete use

The drivers that I identified, which can support the growth of the sustainable concrete market are:

1. Environmental Concerns: Increasing awareness about the environmental impact of traditional concrete production and the need for more sustainable building materials are driving demand for sustainable concrete (Altarrazi et al., 2022; de Brito & Kurda, 2021a).
2. Government Support: Governments around the world are taking steps to promote sustainable building materials, including sustainable concrete, through tax incentives, grants, and other forms of support (Ooa & Ioe, 2017; Shen et al., 2010).
3. Technological Advances: Advances in technology are making it possible to produce sustainable concrete more efficiently and at a lower cost, which is making it a more attractive option for construction projects (Alsanad, 2015).
4. Rising Demand for Energy-Efficient Buildings: The demand for energy-efficient buildings is growing, and sustainable concrete is a material that can help to improve the energy efficiency of buildings, making it more attractive for use in construction projects (Altarrazi et al., 2022).
5. Cost Savings: Sustainable concrete can provide cost savings over the long term, due to its reduced environmental impact and improved energy efficiency, making it a more appealing option for organizations that are looking to reduce their costs (Alsanad, 2015).

6. Consumer Pressure: Consumers are increasingly demanding environmentally friendly products, including building materials, which is driving demand for sustainable concrete (Ooa & Ioe, 2017)(Altarrazi et al., 2022).

Overall, these six drivers can help to support the growth of the sustainable concrete market and are likely to continue to drive its growth in the future.

The successful use of sustainable concrete depends on technical and economic factors as well as societal acceptance. Involving stakeholders and considering social aspects is crucial. Factors supporting its use include environmental concerns, government support, technological advancements, energy-efficient buildings, cost savings, and consumer demand. To guide the transition, a theoretical framework provides a structured approach to assess feasibility, viability, acceptance, and adoption processes (Bergek et al., 2005).

3.4 Theoretical Framework

This chapter focuses mainly on the fundamental ideas that underlie the theoretical framework of the thesis. The aim is to give an initial comprehension of the research topic by setting the context of the theoretical framework.

3.4.1 Technological Transition: the need for an integrated approach

As it is introduced earlier for sustainable concrete, it is important to recognize that the successful implementation of this new technological innovation approach is not only dependent on the technical feasibility and economic viability. The long-term success of this transition to using the material also depends on the societal acceptance and adoption process (Voß et al., 2009). Therefore, it is important to involve stakeholders in the development and implementation process and consider the social context when making decisions about the adoption of this new material(Voß et al., 2009).

Getting information about communities and interest groups' points of view about the transition provides knowledge about the most recent benefits and risks of the technology, and addressing social considerations are key steps in taking a more holistic approach to this new technology implementation (Voß et al., 2009). As a result of this, the likelihood of successful diffusion can be increased, and a greater social and environmental impact is achievable.

To investigate the complexity of transitions in large systems, empirical studies have emerged as a critical tool in the social sciences, such as transportation to use sustainable materials, as well as the development and spread of sustainable innovations. Some scholars argue that a wider perspective is necessary to study sustainability transitions, while traditional approaches to innovation diffusion, such as Roger's theory, have focused on the characteristics of the innovation itself and social factors from the user perspective (Sahin, 2006). This wider perspective considers the interlinked mix of technologies, infrastructures, organizations, markets, regulations, and user practices that together deliver societal function, also referred to as socio-technical systems(Köhler et al., 2019).

3.4.2 Framework Selection for Technological Transition: Evaluation and Rationale

Understanding the capability of transition and adapting to changes within complex systems has been a topic of study for researchers across various disciplines. There are frameworks such as strategic niche management (SNM), transition management (TM), the multi-level perspective (MLP), and technological innovation systems (TIS) that have been developed to provide insights into how these systems evolve over time (Köhler et al., 2019). Strategic niche management (SNM) specifically focuses on the conditions that allow for the emergence of new niches within a system (Schot & Geels, 2008). The MLP involves three levels of analysis: niches, socio-technical regimes, and exogenous landscape developments, and it emphasizes the tension between stability and change, represented by structuration at different levels of analysis (Geels, 2002). TM provides a policy framework with four steps for shaping transitions: strategic vision development, tactical planning and coalition building, operational experimentation and implementation, and reflexive evaluation and monitoring (Loorbach & Rotmans, 2010). SNM focuses on the emergence of radical innovations in protected spaces such as subsidized projects, experiments, or dedicated users, and it involves interactions between learning processes, social networks, and expectations to generate innovation trajectories (Schot & Geels, 2008).

In recent years, there has been a growing interest in the transition from traditional concrete to sustainable concrete. This shift is driven by concerns about the environmental impact of concrete production and the need for more sustainable construction materials. Sustainable concrete is produced using recycled materials, low-carbon cement alternatives, and other eco-friendly additives that reduce the carbon footprint of construction projects. This transition involves multiple actors, including construction companies, material suppliers, policymakers, and consumers (Altarrazi et al., 2022).

After careful consideration, I have chosen the technological innovation systems (TIS) framework to answer my research question. I believe that TIS is the most as it allows a comprehensive analysis of the interaction between technology, actors, and institutions involved in the development of sustainable concrete (Bergek et al., 2008). As my research focuses on implementing sustainable concrete in the Dutch construction industry, the TIS framework offers a useful approach to analyzing the factors that will drive the successful adoption and diffusion of this technology. The TIS framework recognizes the importance of various functions, such as knowledge development and diffusion, entrepreneurial experimentation, and market formation, which are all relevant to my research question (Köhler et al., 2019). Furthermore, the TIS framework can help identify and overcome barriers to sustainability, as demonstrated by a study on source separation in Sweden (McConville et al., 2017). By following the policy recommendations outlined in the TIS framework, such as supporting technical R&D, establishing guidelines and standards for sustainable practices, and promoting communication and collaboration within the industry, the Dutch construction industry can overcome barriers to sustainable concrete and transition towards a more sustainable system (McConville et al., 2017). This is particularly important given the global environmental challenges we face today and the need for innovation and experimentation to develop new, sustainable practices for managing waste and resources. Thus, using the TIS framework will provide a valuable lens for analyzing the key factors influencing the successful adoption and diffusion of sustainable concrete in the Dutch construction industry.

3.4.3 Technological Innovation System

The concept of transitioning from traditional concrete to sustainable concrete can be analyzed through the lens of the Technological Innovation System (TIS) framework. The use of traditional concrete in construction has been associated with significant environmental impacts, including high carbon emissions and depletion of natural resources. In contrast, sustainable concrete aims to reduce these negative impacts using alternative materials and innovative production methods (Surahyo, 2019).

Applying the TIS framework to this transition, the technological regime of sustainable concrete includes the development of new materials, such as recycled aggregates and low-carbon cement, as well as the adoption of new production methods, including carbon capture and utilization (Javadabadi et al., 2019). The institutional regime includes policies and regulations that incentivize the use of sustainable concrete and encourage innovation in this area. The entrepreneurial regime includes actors such as sustainable concrete manufacturers, investors, and researchers who actively seek to introduce and promote sustainable concrete within the construction industry (Zhao et al., 2020).

This thesis uses three structural dimensions: actors, networks, and institutions, based on the recommendations from Bergek et al. (2005). Actors are network members that can be individuals or organizations. This thesis focuses on governmental organizations, knowledge and research institutes, and industrial actors. Institutions are divided into soft institutions, such as people's routines and habits, and hard institutions, such as laws and regulations. Financial institutions, like investment programs and subsidies, and regulatory institutions, such as laws and strategies, are analyzed. Networks are formal and informal collaborations between actors or groups. In this thesis, networks focus on scientific, economic, or political issues as knowledge-developing networks or interest and representative groups (Bergek et al., 2005).

By understanding the interactions between these actors, institutions, and technologies in the TIS of sustainable concrete, policymakers and entrepreneurs can identify barriers and drivers for the development and increase usage of sustainable concrete. The TIS framework can also help to identify strategies for promoting the adoption of sustainable concrete and driving economic growth while reducing environmental impacts (Bergek et al., 2008).

The TIS framework provides a comprehensive and flexible approach to studying technological innovation, which can be applied to the transition from traditional concrete to sustainable concrete, as well as other sustainable innovations. After I identify the dimensions of sustainable concrete that are relevant to the Technological Innovation Systems (TIS) framework, Bergek et al. (2008) highlighted the need to address seven TIS functions. These functions were crucial in developing effective strategies and defining policies to facilitate the transition towards sustainable concrete. The seven functions are outlined in Table *1*.

Table 1: Outlined the functions of the TIS framework along with their corresponding indicators (Bergek et al., 2008)

Functions	Indicators
Knowledge Development	Research and development related to sustainable concrete production methods, including material sourcing, production processes, and performance metrics such as compressive strength, durability, and carbon footprint. Specific indicators could include the number of research studies conducted on sustainable concrete, the number of patents filed for sustainable concrete technologies, and amount of funding allocated to sustainable concrete research and development.
Entrepreneurial Experimentation	Pilot projects and demonstrations of sustainable concrete production methods in real-world settings to test their practicality and performance, including the use of alternative materials and innovative manufacturing techniques. Specific indicators could include: The number of pilot projects implemented, the reduction in carbon emissions achieved through sustainable concrete use, and cost savings realized through sustainable concrete production methods.
Market Formation	Development of a market for sustainable concrete products and services, including partnerships with industry and government to promote sustainable building practices and the adoption of green building standards. Specific indicators could include The number of sustainable concrete products available in the market, the market share of sustainable concrete, and number of partnerships established to promote sustainable building practices.
Creation of Societal Demand	Public awareness campaigns and educational programs to increase awareness and acceptance of sustainable concrete technologies and their environmental benefits, and to address concerns related to safety, cost, and performance. Specific indicators could include: The number of public awareness campaigns launched(agreements), the number of people(companies) reached through these

	campaigns, and changes in consumer attitudes and behaviors related to sustainable concrete use.
Shaping of Technology Trajectories	Government policies and regulations incentivize the development and adoption of sustainable concrete production methods, including subsidies, tax incentives, and regulations on emissions and building codes. Specific indicators could include the number of policies and regulations implemented to promote sustainable concrete use, reduction in carbon emissions achieved through policy interventions, and increase in the adoption of sustainable concrete practices by the building industry and regulations that make the transition harder.
Building of Innovation Networks	Collaboration with industry, academia, and government to promote innovation and knowledge sharing in sustainable concrete technologies, including research partnerships and technology transfer programs. Specific indicators could include the number of partnerships established to promote sustainable concrete innovation and knowledge sharing, the number of joint research projects undertaken, and number of technology transfer agreements signed.
Fostering of Sociotechnical Acceptance	Engaging stakeholders and the public in the development and implementation of sustainable concrete technologies to address potential concerns and ensure sociotechnical acceptance, including stakeholder workshops, participatory design processes, and public engagement activities. Specific indicators could include the number of stakeholder workshops held, the number of participants in these workshops, and changes in stakeholder attitudes and behaviors related to sustainable concrete use.

The chosen methodology for this research aligns with the established theoretical framework of sustainable concrete implementation. By employing the Technological Innovation System (TIS) framework, the methodology systematically assesses the dimensions and factors involved in the transition to sustainable concrete. This connection ensures a structured approach to investigate and analyze the implementation process in line with the principles of the TIS framework.

4. CHAPTER 3: METHODOLOGY

In this section, I introduce the research design and methodology for this study. To provide a comprehensive overview of the study, I have described the research framework, strategy, data collection methods, and data analysis methods that are employed to answer the research questions. By doing so, I have ensured that the research approach is valid, and the chosen methods are justified to achieve the research objectives.

4.1 Research Strategy

The aim of this research is to propose policies that can support the acceleration of the transition towards a more sustainable building industry in the Netherlands. This is achieved through the determination of the level of adaptation for sustainable concrete and the identification of drivers and barriers that influence construction companies to shift towards sustainable concrete. Additionally, the research analyzes the interaction between these drivers and barriers using Transition Innovation System (TIS) functions. To achieve this, I employ the methodology described in Table *2*:

Table 2: Methodology to answer sub-questions

Research (Sub)-Question	Data/Information required to answer question	Sources of data	Type of data
What is the current level of adoption of sustainable concrete in the construction industry in the Netherlands in terms of reduction in CO2 emission percentage?	The current state of adoption within the different phases of the Dutch construction industry to sustainable concrete considering the dimensions of a TIS	Secondary Data published articles, reports	Secondary Data published articles, reports
		Primary Data:	Primary Data:
		People: Including in the Dutch Concrete Agreement	Including answers to surveys and interviews from people included in Dutch Concrete Agreement
What are the drivers and barriers that affect Dutch construction companies to implement sustainable concrete?	Finding drivers and barriers in the context of social, economic, and technical	Secondary Data published articles, reports, books, and policy documents	Secondary Data published articles, reports, books, and policy documents
		Primary Data	Primary Data:
		People: gov. auth., construction companies, research institutes, etc.	Including answers to Surveys, Interviews from People gov. auth., construction companies, research institutes, etc.
Considering TIS functions (drivers and barriers), how to accelerate the transition to a more sustainable building industry?	Providing a solution to accelerate the transition	Using Answers from the previous question and TIS analysis	Secondary Data published articles, reports, books

4.2 Research Unit

The research unit for this study is the Dutch construction industry, with a focus on the adoption of sustainable concrete. The construction industry is a complex and diverse sector that involves multiple actors, including construction companies, architects, engineers, suppliers, and policymakers. The first part of the study aims to investigate the current level of adoption of sustainable concrete within the different phases of the construction industry in the Netherlands, including design, production, transportation, and construction. The research unit is relevant to the study's research questions, which aim to identify the drivers and barriers for construction companies to transition towards sustainable concrete and to provide solutions to accelerate the transition to a more sustainable building industry. The study collected both primary and secondary data from various sources, including published articles, reports, books, policy documents, and interviews with key stakeholders such as government authorities, construction companies, research institutes, and others involved in the Dutch Concrete Agreement. The analysis used TIS dimensions to identify the key factors influencing the adoption of sustainable concrete in the construction industry and to provide recommendations for accelerating the transition towards more sustainable practices.

4.3 Data Sources and collection methods

4.3.1 Literature review

A literature review is a summary of published work in a field of study, serving as a tool for justifying research questions and providing a summary for other researchers (Conduct a Literature Review, 2023). The literature review is a critical component of this study, providing a comprehensive understanding of the current state and prospects of sustainable concrete adoption in the Dutch construction industry. To accomplish this, I conducted an extensive search of published articles, reports, and policy documents related to sustainable concrete and the Dutch construction industry, utilizing online databases such as Scopus, Web of Science, and Google Scholar.

To ensure a robust literature review, I focused on methodology papers and other relevant literature to identify the different drivers and barriers for construction companies to shift towards sustainable concrete, the current state of adoption of sustainable concrete within different phases of the Dutch construction industry, and the existing interaction between drivers and barriers to accelerate the transition to a more sustainable building industry. Furthermore, I identify any relevant studies, reports, and other publications that describe sustainable concrete and its actors in the Netherlands. Through this review, I identify the drivers and barriers impacting the adoption of sustainable concrete in the Netherlands, along with any potential challenges and opportunities for future progress.

4.3.2 Interviews

In the field of social sciences, researchers use a method called a semi-structured interview to gather data by asking open-ended questions based on a predetermined theme. Unlike a structured interview, this approach provides flexibility for new ideas to arise during the interview, allowing interviewees to better express themselves (Tegan George, 2022). Both the interviewer and the participant engage in a conversation and exchange questions and answers (Knott et al., 2022). The interviews are a critical element of this study, providing a deeper understanding of the perspectives and experiences of key stakeholders involved in the adoption of sustainable concrete in the Dutch construction industry. I select interviewees based on their expertise and involvement in the sustainable concrete innovation system, including government authorities, construction companies, research institutes, and other stakeholders.

To ensure that the interviews provide a comprehensive understanding of the socio-technical aspects of the innovation system, I formulate interview questions based on the dimensions of the Technological Innovation System (TIS) framework. The TIS framework helps me identify the current and emerging socio-technological innovations in the sustainable concrete domain. I conduct the interviews ensuring that all relevant dimensions of TIS are covered.

All interviews are recorded, transcribed, and analyzed using qualitative data analysis software to identify key themes and patterns. The results of the interviews provide insights into the current level of adoption of sustainable concrete in the construction industry in the Netherlands and the drivers and barriers to its adoption.

4.4 Research questioner

To effectively utilize the TIS framework and gather comprehensive information, I need to make sure that the questionnaire covers all the relevant areas that need to be surveyed. This means asking the participants about every aspect related to the TIS framework. By doing this, I can get a better understanding of the subject matter.

I have designed the questionnaire in Table *3* to cover different dimensions of the TIS framework. It aims to explore each function in detail, so I can gather valuable insights and have a complete view of the TIS framework. The appendix III contains text version of the questionnaire.

To make sure the questions are effective and align with my research goals, I have added extra columns called "probable drivers" and "probable barriers". These columns help me identify the factors that can either support or hinder the implementation of the TIS framework. By considering these factors, I can draw more informed conclusions and make better recommendations based on my research.

Expanding and refining the questionnaire in this way gives me a strong foundation for collecting data and conducting a thorough analysis. It allows me to explore the different aspects of the TIS framework and understand how various factors can impact its success.

Table 3 - Questioner table

Functions	Questions	Probable Drivers	Probable Barriers
General questions	What is your current job title?		
	How many years of experience do you have in your field?		
	What is your highest level of education achieved?		
Knowledge Development	What do you think Sustainable Concrete (SC) means?	Technological Advances	Access to Financing, Lack of Awareness
	To what extent are research and development related to SC done in the Dutch construction industry? (Please provide a range of answers, from very low to very high) Additionally, can you share specific examples of SC technologies that you are familiar with?		
	Is there enough funding allocated to SC research and development in the Netherlands?		
Entrepreneurial Experimentation	Have you ever been part of a project that used SC? If so, what were some of the challenges faced during the project?	Environmental Concerns, Cost Savings	Cost, Technical Challenges
	To what extent are environmental concerns considered when implementing SC in a project?		
Market Formation	Is the material for SC easily accessible and is there enough available for entire construction projects?	Rising Demand for Energy-Efficient Buildings	Limited Availability, Resistance from Suppliers
	In your opinion, does the initial higher cost of using SC is seen as an investment by the customers?		
	Do you think that the availability of SC can continue to meet the growing demand in construction projects?		
Creation of Societal Demand	Do you think SC is a reliable material for long-term construction? SC construction, depending on the people we are asking, can be changed.	Consumer Pressure	Perception of Quality
	Approximately what percentage of your clients order SC for their structures? What the volume is?		
Shaping of Technology Trajectories	Are you aware of any regulations or policies that are hindering the transition to the use of SC/Sustainable Construction?	Government Support	Regulatory Barriers
	Are you aware of regulations that support the transition to the use of SC?		
Building of Innovation Networks	Are you part of collaborations between industry, academia, and government to promote innovation and knowledge sharing in SC technologies, and what specific outcomes were achieved because of these collaborations?	Consumer Pressure	Lack of Awareness, Resistance to Change
Fostering of Sociotechnical Acceptance	What strategies have been used in the Dutch construction industry to engage stakeholders and the public in the development and implementation of SC technologies, and what specific outcomes were achieved as a result of these efforts?	Environmental Concerns, Government Support	Resistance from Suppliers
	What factors can contribute to stakeholders and customers being resistant to the adoption of SC practices?		

4.5 Data Analysis

In this study, I aim to analyze the findings from the literature review and interviews, with a focus on the outcomes of the first and second sub-questions. For this purpose, I examine the information obtained from the literature review and interviews in detail, to better understand the results related to the first and second sub-questions. Then, I use the TIS analysis to identify strategies and propose policies that can help accelerate the transition towards sustainable concrete and address the third sub-question.

4.6 Ethical Considerations

The study involved collecting information through interviews with human participants. It was crucial to obtain the participants' consent before conducting the interviews. The participants were informed in advance about various aspects, including the voluntary nature of their participation, the purpose and nature of the investigation, the right to decline participation or withdraw from the research without facing any negative consequences, and the identity of the researcher.

The participants willingly agreed to be part of the research and were provided with an understanding of the study's objectives. They were also given the option to discontinue their involvement during the research process. This ensured that the participants had control over their own participation. To formalize their consent, each participant received a consent form before the interview, which they read and signed if necessary. Sample consent forms can be found in Appendix II. Regarding confidentiality, if any participant requested the preservation of information confidentiality or anonymity, the researcher made sure to honor their request.

During the interviews, utmost care was taken to protect the integrity of the participants by considering their interests and reputation.

5. CHAPTER 4: FINDINGS

5.1 Background of sustainable concrete in the Netherlands

Before I start the TIS (Technological Innovation System) analysis, I introduce the current situation of the construction industry especially sustainable concrete in the Netherlands. This is considering the 2015 Paris Agreement, a deal where countries in the European Union, including the Netherlands, agreed to lower their greenhouse gas emissions by 2030 and 2050. After this agreement, these countries started working hard towards this goal, making changes across different business sectors.

In the Netherlands, the building industry took big steps towards being more eco-friendly in 2017 by introducing a policy on the circular economy. This policy aimed to get different construction sectors to work together to achieve the goals outlined in the Paris Agreement by 2030 and 2050. It encouraged changes and promises from the people involved in the building industry to work in line with sustainable development principles (Bijleveld & Beeftink, 2017).

A great example of cooperation within the Dutch concrete industry came up in 2018. This cooperation called the "Beton Akkoord" (Concrete Agreement), united 82 different parties from various parts of the industry. The Concrete Agreement was a big achievement, as the companies involved agreed to follow a detailed plan aimed at reaching the sustainability goals set in the Paris Agreement. With this agreement, the concrete industry in the Netherlands started a journey to lower its impact on the environment, be more resource-efficient, and promote sustainable practices.

After the Concrete Agreement was set up, a lot of events and meetings have been organized to help the concrete industry meet the targets outlined in the Paris Agreement. These events provide places for sharing knowledge, working together, and sharing the best ways of doing things among industry workers, research institutes, government bodies, and other relevant actors. The combined efforts of these stakeholders are important in driving innovation, advancing technology, and encouraging the use of sustainable practices throughout the concrete industry.

These efforts have also led to partnerships between the public and private sectors, creating a good environment for shared research and development projects. By bringing together resources and expertise, these collaborations could speed up the implementation of sustainable solutions, such as low-carbon concrete mixes, innovative building techniques, and better waste management practices. Through these partnerships, stakeholders can use their combined strengths and navigate the complexities of the concrete industry, effectively promoting sustainable growth and environmental care.

The TIS framework is a useful tool to analyze and understand the dynamics of technological innovation systems. It covers various areas, including actors, networks, and institutions. Multiple methods can be used to do a full analysis using the TIS framework (Bergek et al., 2008). One effective method is conducting interviews and discussions with technology or industry experts. These discussions provide valuable insights into the roles and interactions of different actors within the technological innovation system.

During an interview with members of the Concrete Agreement, key information regarding the actors in the construction industry in the Netherlands was obtained. **Error! Reference source not found.** shows the important actors involved in the industry and their respective roles. These actors and their relations have been illustrated using reports about the concrete industry in the Netherlands (Bijleveld & Beeftink, 2017; Peter of Ghent, 2021).

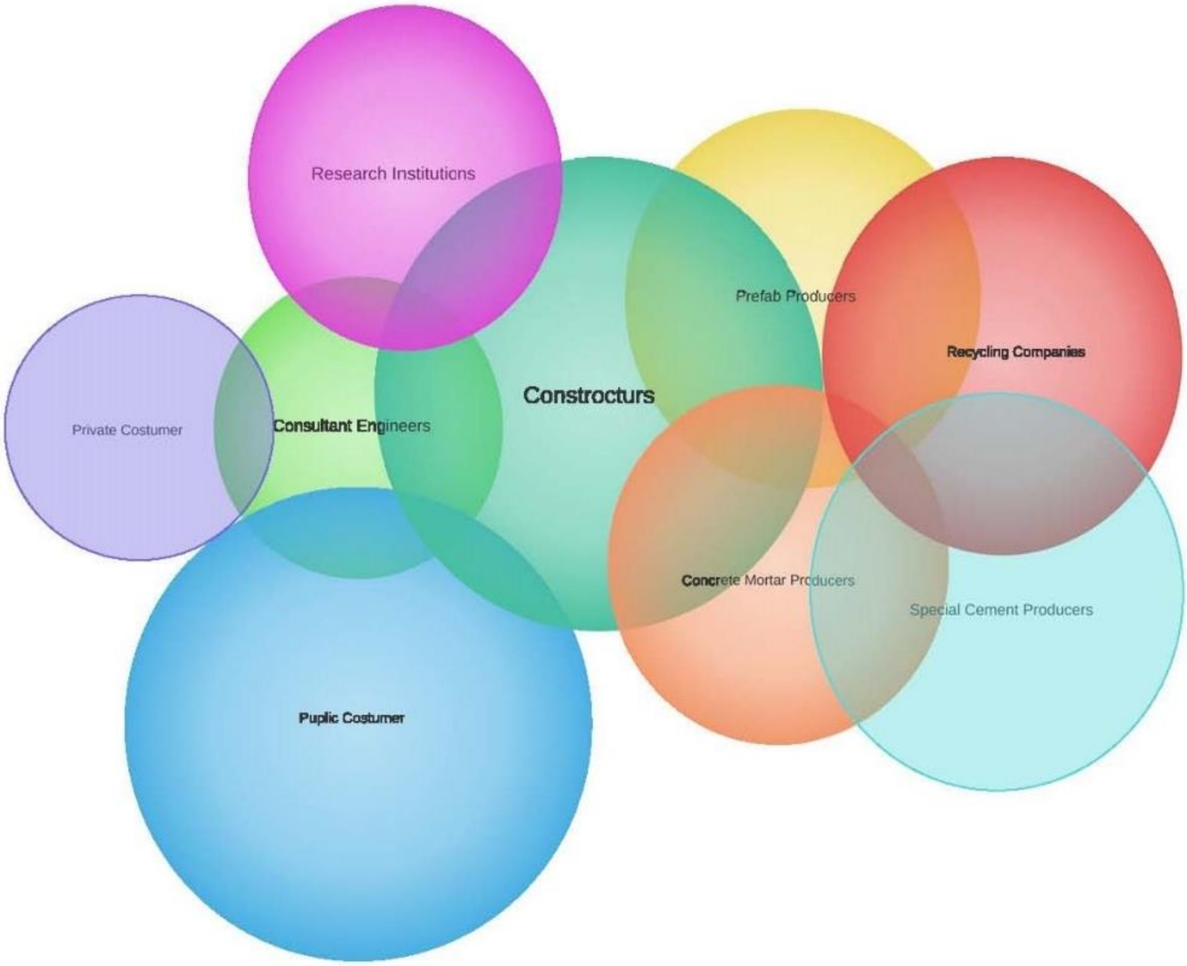

Figure 1-Actors in the concrete sector

To use concrete as a construction material in projects, customers play a crucial role as they are the ones who order the needed material. In the Netherlands, both public and private companies serve as customers, ordering concrete for their specific projects. It is important to note that the decisions made by customers regarding concrete orders are often influenced by the design specifications provided by consultant engineering companies. Therefore, the key actors involved in the ordering process of concrete include public and private companies, as well as consulting engineers. These actors work together to define the requirements and characteristics of the concrete needed for each project.

Once the order for concrete is placed, the production phase begins. Two common types of concrete used in construction projects are prefabricated concrete and concrete mortar which is a paste-like substance including a mixture of cement, sand, and water used as a bonding agent in construction to join building units together and poured on construction sites. The actors influencing the production of prefabricated concrete differ from those involved in the production of concrete mortar. For prefabricated concrete, specialized companies or construction firms often have their factories dedicated to making this type of concrete. On the other hand, for concrete mortar, suppliers typically produce the material. In cases where large projects make on-site concrete preparation more feasible, the construction company may set up a small-scale concrete mortar factory at the project site. Therefore, the actors involved in producing different types of concrete mortar include construction companies, prefabricated concrete factories, and concrete mortar factories.

Several key materials are mixed in the concrete production process, including cement, aggregates, and water. To make concrete more sustainable, the involvement of additional actors becomes crucial. Recycling companies play a big role by providing recycled aggregates and cement, which reduces the use of new materials and lowers the environmental impact associated with concrete production. Additionally, some cement factories are dedicated to making cement with a lower carbon footprint, using new manufacturing processes and alternative raw materials. These actors help make the concrete industry more sustainable and resource efficient.

Research institutes also have a crucial role in the concrete sector. As the industry tries to use new types of materials and technologies to make sustainable concrete, it's important to test these innovations to see how they perform. Research institutes carry out detailed investigations to analyze the characteristics, structural integrity, durability, and environmental impact of sustainable concrete under various conditions. This knowledge is important to make sure that sustainable concrete meets the necessary standards and can be confidently used in construction projects.

In the Netherlands' concrete industry, there are many key actors involved, including public and private builders, consulting engineering companies, prefabricated concrete producers, concrete mortar producers, recycling companies, specific cement factories, and research institutes. Each of these actors plays a pivotal role in establishing a comprehensive network, where their insights into sustainable concrete and its relation to TIS functionality hold significant importance. In the following sections, I describe each actor and explain their relationships. I then introduce the institutional sector of the framework.

5.2 Dimensions

To understand the dimensions of the concrete industry in the Netherlands, an examination of relevant reports on the subject was conducted. Specifically, the reports by Bijleveld and Beeftink (2017) and Peter of Ghent (2021) were utilized to gain insights into the key actors and their roles within the industry. These reports provided valuable information on the actors involved, their relationships, and the overall structure of the concrete industry in the Netherlands.

5.2.1 Actors and Network:

Customers: In the Netherlands, both public and private companies serve as customers in the concrete industry. These customers play a crucial role in the network by placing orders for the required concrete materials for their construction projects. They interact with various actors within the network, such as consultant engineering companies, construction companies, prefabricated concrete producers, concrete mortar producers, recycling companies, specific cement factories, and research institutes, to communicate their concrete requirements and ensure smooth project execution.

Consultant Engineering Companies: Consultant engineering companies influence the decisions made by customers regarding concrete orders. They provide design specifications and technical expertise to guide customers in selecting the appropriate concrete materials for their projects. Their collaboration with customers and other actors in the network helps define the requirements and characteristics of the concrete needed for each project.

Construction Companies: Construction companies play a vital role in the production phase of concrete. They collaborate with customers, consulting engineering companies, prefabricated concrete producers, concrete mortar producers, recycling companies, specific cement factories, and research institutes. Construction companies ensure the seamless execution of projects by coordinating with different actors in the network to procure the required concrete materials and oversee the construction process.

Prefabricated Concrete Producers: Prefabricated concrete producers have their dedicated factories for manufacturing pre-made concrete elements. They contribute to the network by supplying prefabricated concrete materials to construction companies and customers. Their collaboration with other actors in the network ensures a steady supply of high-quality prefabricated concrete for various construction projects.

Concrete mortar Producers: Concrete mortar producers supply on-site concrete for construction projects. They interact with the network's construction companies, customers, and recycling companies to provide the required concrete mortar materials. In some cases, construction companies may establish small-scale concrete mortar factories at project sites, further integrating concrete mortar producers into the network.

Recycling Companies: Recycling companies play a significant role in enhancing the concrete industry’s sustainability. They provide recycled aggregates and cement, reducing the consumption of virgin materials and minimizing the environmental impact. Recycling companies collaborate with customers, construction companies, and specific cement factories in the network to promote the use of recycled materials, contributing to a more sustainable and resource-efficient concrete production process.

Specific Cement Factories: Specific cement factories focus on producing cement with a lower carbon footprint. They employ innovative manufacturing processes and alternative raw materials, reducing the environmental impact of cement production. These factories collaborate with customers, recycling companies, and research institutes in the network to ensure the availability of sustainable cement options for the concrete industry.

Research Institutes: Research institutes play a vital role in the concrete industry network. They conduct comprehensive investigations and research to analyze sustainable concrete characteristics, structural integrity, durability, and environmental impact. Research institutes collaborate with customers, consulting engineering companies, construction companies, prefabricated concrete producers, concrete mortar producers, recycling companies, and specific cement factories to share knowledge and advancements. Their research findings guide the industry towards innovative practices and contribute to the overall development of sustainable concrete solutions.

These network connections highlight the interdependencies and collaborations among different actors within the concrete industry in the Netherlands. The interactions and information exchange among these actors ensure the smooth functioning and growth of the industry as a whole

5.2.2 Institutions:

The institution dimension of the framework encompasses the regulatory bodies, industry associations, and organizations that govern and support the concrete industry in the Netherlands. These institutions provide guidelines, regulations, and standards for quality assurance, safety, and environmental considerations. They play a crucial role in ensuring the compliance of actors within the network and promoting best practices. Some key institutions in the concrete industry of the Netherlands include:

Regulatory Bodies: Regulatory bodies, such as government agencies and local authorities, establish and enforce regulations and building codes related to the production, transportation, and use of concrete. These bodies ensure that construction projects adhere to safety standards, environmental regulations, and other legal requirements.

Industry Associations: Industry associations bring together different stakeholders in the concrete industry, including customers, consulting engineering companies, construction companies, prefabricated concrete producers, concrete mortar producers, recycling companies, specific cement factories, and research institutes. These associations facilitate collaboration, knowledge sharing, and advocacy for the industry. They organize events, seminars, and training programs to foster networking and professional development within the industry.

Research Institutions: Research institutions, including universities and dedicated research centers, contribute to the institutional landscape of the concrete industry. They undertake fundamental and applied research to advance knowledge and innovation in concrete technology, sustainability, and performance. Research institutions often collaborate with industry actors, providing expertise and conducting research projects that address the industry's challenges and drive its development.

Certification and Accreditation Bodies: Certification and accreditation bodies play a vital role in ensuring quality control and compliance within the concrete industry. These bodies certify the production processes, materials, and systems used by actors in the network. They establish standards and protocols for quality assurance, environmental management, and product certification, providing credibility and assurance to customers and other stakeholders.

Sustainability Initiatives and Organizations: Various sustainability initiatives and organizations focus on promoting sustainable practices within the concrete industry. These entities work towards reducing carbon emissions, promoting circular economy principles, and enhancing resource efficiency. They collaborate with actors in the network to develop sustainable concrete solutions, support research and development efforts, and disseminate best practices.

The institutions within the concrete industry framework provide the necessary guidelines, regulations, support, and expertise to ensure the industry operates safely, efficiently, and sustainably. They create an environment conducive to innovation, knowledge exchange, and continuous improvement. The collective efforts of these institutions and their collaborations with actors in the network contribute to the overall development and advancement of the concrete industry in the Netherlands.

5.3 Level of Adaptation of sustainable concrete in the Dutch construction industry

This part focuses on answering the first research sub-question of my thesis, which explores how much sustainable concrete is currently being used in the construction industry in the Netherlands. I have gathered specific information and data to gain insights into the level of adoption in different phases of the construction industry, considering the dimensions of a Technological Innovation System (TIS).

Table 2 outlines the method I used to answer this sub-question, including the types of data I need and where I find it. I have relied on both secondary and primary data sources to thoroughly examine the adoption of sustainable concrete.

Secondary data refers to existing articles and reports that have studied the topic of sustainable concrete adoption in the Dutch construction industry. These sources provided the research with valuable information and research already conducted. By analyzing and summarizing this existing data, I aim to develop an understanding of how widely sustainable concrete is currently being used.

In addition, I recognize the importance of collecting primary data to gather insights and perspectives directly from key stakeholders. I have engaged with individuals involved in the Dutch Concrete Agreement (Beton Akoord), conducting interviews. This primary data collection helps me gather firsthand information about the expectation for the use of sustainable concrete in the construction industry.

In the following Figure 2, the road map CO2 for the concrete industry in the Netherlands has been illustrated and the goals and its path be discussed.

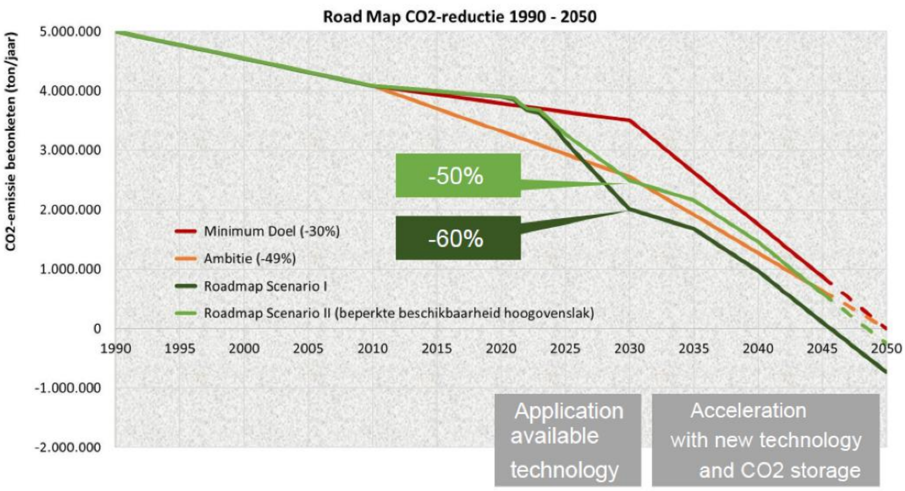

Figure 2- Concrete Road map for Co2 reduction(Peter of Ghent, 2021)

The Road Map CO2 serves as a strategic blueprint for the entire concrete sector in the Netherlands, outlining a comprehensive set of measures to achieve the ambitious CO2 reduction targets established in the Concrete Agreement NL. The agreement, signed on July 10, 2018, sets out the goal of reducing CO2 emissions by a minimum of 30% by 2030, with an even more ambitious aim of a 49% reduction. This long-term plan envisions eliminating CO2 emissions in the concrete sector by 2050, compared to the levels produced in 1990 (Peter of Ghent, 2021).

The Road Map CO2 provides an extensive overview of action perspectives that can be pursued to effectively reduce CO2 emissions in the concrete sector. It is important to note that the sum of these perspectives goes beyond the defined reduction targets, ensuring a comprehensive and robust approach to carbon reduction. The Road Map is not intended as a prediction of future CO2 reduction, but rather as a descriptive framework that offers a range of potential strategies and initiatives.

The mentioned guideline for CO2 reduction adopts a flexible approach, presenting various possible routes for achieving the reduction targets. It emphasizes the active participation and collaboration of all stakeholders involved in the concrete sector. This strategy differentiates between realistic reduction scenarios (minimum 30%) and more ambitious targets (49%). The development and support of the Road Map involved representatives from the entire concrete sector, ensuring a broad perspective and expertise. The classification of action perspectives is based on the Building Values Model, with calculations and justifications rooted in the knowledge and experience of participants, supplemented by relevant public reports and scientific insights.

The primary objective of the Road Map CO2 is to achieve a 30% reduction in CO2 emissions in the concrete chain by 2030, compared to the levels recorded in 1990. Furthermore, there is an ambitious target of a 49% reduction by the same year. To illustrate the significance of these goals, it is worth noting that in 2017, CO2 emissions in the concrete sector were primarily attributed to concrete material (68%), reinforcing steel (21%), transport to construction sites (8%), and construction, demolition, and preparation for reuse (3%). These activities are analyzed separately to get a clearer picture of the concrete sector. The Road Map sets milestones based on historical emissions, aiming for a reduction of 1.55 million tons of CO2 between 2010 and 2030, and an additional reduction of 1.25 million tons of CO2 between 2017 and 2030 (Bijleveld & Beeftink, 2017).

The CO2 pathway presents a range of action perspectives that can be implemented independently of each other. While it is challenging to precisely determine the individual impact of each perspective in advance, their combined effect is expected to surpass the intended reduction targets. Even in a pessimistic scenario where the availability of fly ash completely disappears and the use of blast furnace slag is halved, the action perspectives outlined in the Road Map are projected to exceed the 30% (or 49%) target. The theoretical total reduction potential from the individual perspectives is estimated to be approximately 60%, indicating a significant buffer above the 49% target (Peter of Ghent, 2021). However, practical considerations, such as interdependencies and stacking effects among certain action perspectives, may limit the total achievable reduction potential.

This Action plan presents two distinct scenarios for reducing CO2 emissions. Scenario I (-60%) considers the limited availability of fly ash, while still achieving a cumulative reduction that exceeds the 49% target. Scenario II (-50%) assumes a halving of Dutch blast furnace slag availability by 2030, while still working towards the desired reduction targets (Peter of Ghent, 2021).

The CO2 reduction ambitions outlined in the Concrete Agreement are indeed feasible, even in worst-case scenarios. While cement production plays a significant role in CO2 emissions, it is important to recognize that achieving the reduction targets requires collective action and collaboration from all stakeholders within the concrete sector. Successful implementation of the action perspectives necessitates early coordination, effective knowledge sharing, and a unified effort among all actors involved. Furthermore, many of the proposed action perspectives are already applicable without the need for major technological innovations, although the lack of economic incentives may hinder their widespread adoption. Knowledge transfer and sharing throughout the concrete sector are key in accelerating the application of these action perspectives and driving sustainable change.

To assess the progress of the concrete sector toward its goals, it is crucial to validate whether the industry is advancing as predicted. A key factor in determining the current situation is the volume of materials used within the concrete sector. To accurately calculate this volume, a recently launched application has been made available for all concrete producers to enter data on the number of materials utilized and their respective sources. This information can give insights into the industry's use of sustainable materials and the associated decrease in CO2 emissions that each firm has accomplished. It includes the usage of all material parts including concrete mortar mixture.

Given that the application was just recently published, the associated data is expected to become available throughout the summer and be updated regularly. This gives the concrete sector ability to evaluate this transition regularly. Unfortunately, owing to time restrictions in my study, I was unable to directly use this data. However, to acquire insight into the present stage of adaption, I conducted two interviews with concrete specialists, and their overall information is presented in Table 4. Surprisingly, both analysts shared a similar assessment of the industry's current state.

Table 4 - Participants' information for the level of adaptation

Participant Code	Job title	Experience	Area of Experience
MP01	Consultant	25 years	Structural engineering / concrete technology/geotechnics / innovation
MP02	Sustainability adviser	32 years	Concrete technology, especially durability, sustainability, and circularity of concrete

According to these experts, the concrete sector in the Netherlands exhibits a combination of positive and negative aspects. On a positive note, substantial progress has been made when compared to the starting point outlined in the roadmap. The industry has successfully achieved a fifty percent reduction in emissions, based on the data released in 2017. This significant advancement represents a commendable achievement and offers a promising outlook for the future.

However, the two experts through the interviews highlighted that achieving the remaining reduction targets will require a substantial amount of effort and collaboration among stakeholders. Regrettably, the current rate of reduction falls short of expectations and is below the predicted target. This discrepancy underscores the necessity for heightened dedication and coordinated action from all parties involved to bridge the gap between the current state and the desired level of emissions reduction.

To address these challenges, stakeholders within the concrete sector must come together and foster partnerships that drive innovation and sustainability. By leveraging their collective expertise and resources, the industry can collaboratively work towards meeting and surpassing the anticipated reduction goals. It is important that concrete producers, suppliers, contractors, policymakers, and other stakeholders cooperate in identifying and implementing effective measures that drive sustainability and further mitigate the environmental impact of the sector.

There is still significant work ahead while acknowledging the progress made by the concrete industry in reducing emissions. By recognizing the existing gaps, promoting collaboration, and implementing targeted measures, the industry can pave the way for a more sustainable future that aligns with both environmental objectives and societal expectations. The forthcoming release of data through the application will provide valuable insights to guide future strategies and initiatives in the pursuit of a greener and more resilient concrete sector in the Netherlands.

Recognizing the significance of the status of sustainable concrete adoption and the requirement for additional efforts, my research aims to identify the drivers and barriers within this sector. To address the second sub-question of this survey effectively, I gathered primary data from industry experts who possess extensive knowledge and experience in the field.

To gather valuable insights into the determinants of progress and roadblocks in sustainable concrete practices, I actively engage with knowledgeable individuals. Their mastery of the subject offers a broad view of the industry's inner workings, highlighting the triggers of advancement and the hindrances to it.
Through in-depth interviews or structured surveys, I explore various aspects of sustainable concrete adoption, including the motivating factors that inspire companies to embrace sustainable practices. These may include environmental considerations, regulatory frameworks, market demand for eco-friendly solutions, and the potential for cost savings and operational efficiencies. By understanding these drivers, we can identify the key elements that encourage the industry's transition toward more sustainable concrete production.

Conversely, the data collected from industry experts also shed light on the barriers and challenges faced by concrete producers in adopting sustainable practices. These hurdles may encompass technical limitations, lack of awareness or understanding, financial constraints, resistance to change, and the availability or accessibility of sustainable materials and technologies. By examining these barriers, we can pinpoint areas that require attention and devise strategies to overcome them, thus fostering greater adoption of sustainable concrete practices.

By utilizing primary data obtained directly from experts within the concrete industry, my research provides an insightful analysis of the drivers and barriers influencing sustainable concrete adoption. These findings will contribute to a comprehensive understanding of the industry's current state and inform the development of targeted interventions and strategies to further propel its progress.

5.4 Findings relating to TIS functions

After realizing the need to speed up the adoption of Sustainable Construction (SC) in the Dutch construction industry, I conducted a survey involving ten experts from the concrete sector in the Netherlands. The survey consisted of two parts: three general questions and fifteen specialized questions. Now, I share the answers provided by these specialists regarding the seven functions of the Technology Innovation System (TIS) framework.

5.4.1 General questions

In the actor section of the TIS dimension, it is evident that there are multiple stakeholders involved in the concrete sector of the Dutch construction industry. To ensure a comprehensive perspective, I tried to include a diverse range of viewpoints. Consequently, I conducted surveys with approximately one hour needed time to fill in, with individuals possessing specialized knowledge and experience, as highlighted in Table 5. It is worth noting that all the participants have extensive expertise in the field of concrete within the Netherlands.

Table 5 - General information about participants

Participant Code	Job title	Experience	Area of Experience
P01	Materials technology Specialist	25 years	Concrete technology, especially durability, sustainability, and circularity of concrete
P02	Sustainable Manager	35 years	The whole spectrum of infrastructure
P03	Consultant	19 years	Asset management, research to extend the service life of concrete structures, re-use concrete/elements, and development of alternative binders
P04	chain director for building materials	25 years	Concrete, asphalt
P05	Construction expert.	15 years	Engineering, the science of structural and cement chemical concrete technology on the applied part of the science.
P06	Consultant	25 years	Structural engineering / concrete technology / geotechnics / innovation
P07	Structural engineer	13 years	(Prestressed) concrete bridges and viaducts, cut and cover tunnels
P08	Sustainable Manager	12 years	Architecture, business administration, management, mechanical engineering, concrete technology, public housing, concrete agreement, environmental impact, circular entrepreneurship: design and production, logistics, inspection, accounting
P09	Sustainability adviser	32 years	Concrete technology, especially durability, sustainability, and circularity of concrete
P10	Program manager circular economy (CE)	20 years	Construction, sustainability, program, and project management

5.4.2 Specialized questions

To understand the participants' knowledge and opinions on sustainable concrete concerning the seven functions of the TIS framework, I conducted a survey with fifteen questions. In this section, I provide an overview of their responses for each function.

Function 1-Knowledge Development

The function of Knowledge Development is essential for advancing sustainable concrete technologies. It focuses on improving material sourcing, production processes, and performance metrics. Indicators of progress include research studies and funding for sustainable concrete research and development. Participants' views on Knowledge Development were gathered through three questions regarding the definition of Sustainable Concrete (SC), the extent of research and development in the Dutch construction industry, and funding allocation for SC research and development in the Netherlands. To find out the point of participants' view about "the Knowledge Development" function, three questions mentioned below have been asked and the following answers are reported.

By answering the first question, I could determine whether their definition of SC aligns with my research.

1. According to your perspective, how would you define Sustainable Concrete (SC)?

I found that all the answers were in line with my research, and each of them included environmental concerns in their definitions. Figure *3* demonstrates the quality of their definition. To assess the quality of the definition, I analyzed it across three distinct categories: comprehensive, adequacy, and brief. If the definition covered three or more distinct aspects of the subject, it was considered comprehensive. For the fewer numbers of aspects, it was adequate and brief respectively.

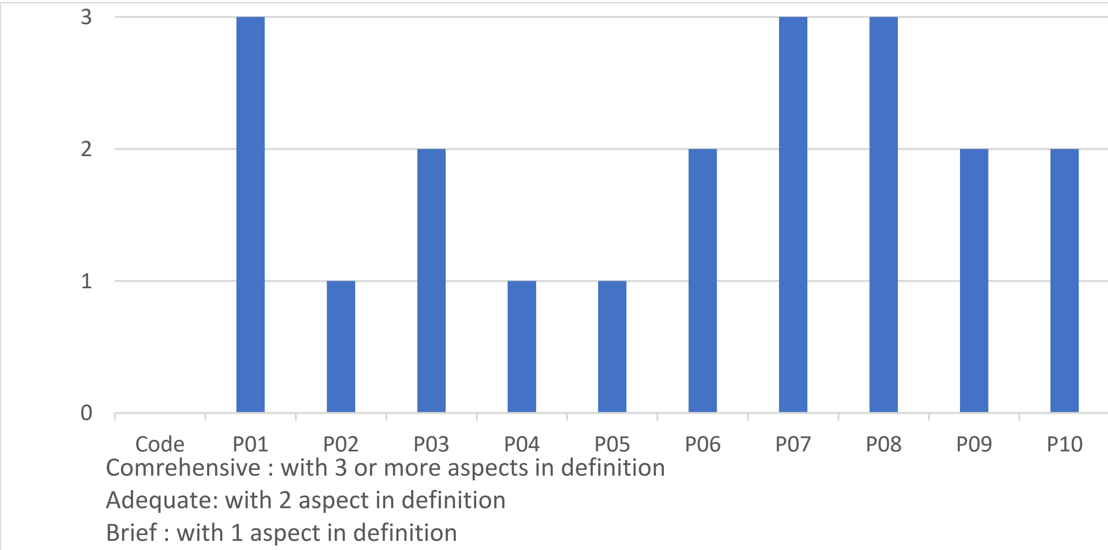

Figure 3-Definition quality

The second question reveals what the participants expect in terms of research and development in the concrete sector, and it assesses their knowledge about different methods for making concrete sustainable.

2. In your opinion, to what extent are research and development related to SC in the Dutch construction industry? (Please provide a range of answers, from very low to very high) Additionally, can you share specific examples of SC technologies that you are familiar with?

The subsequent figures provide a clear illustration of their responses. Figure 4 illustrates the first part of the question with the asked range and Figure 5 shows the number of technologies mentioned by each participant to make concrete sustainable.

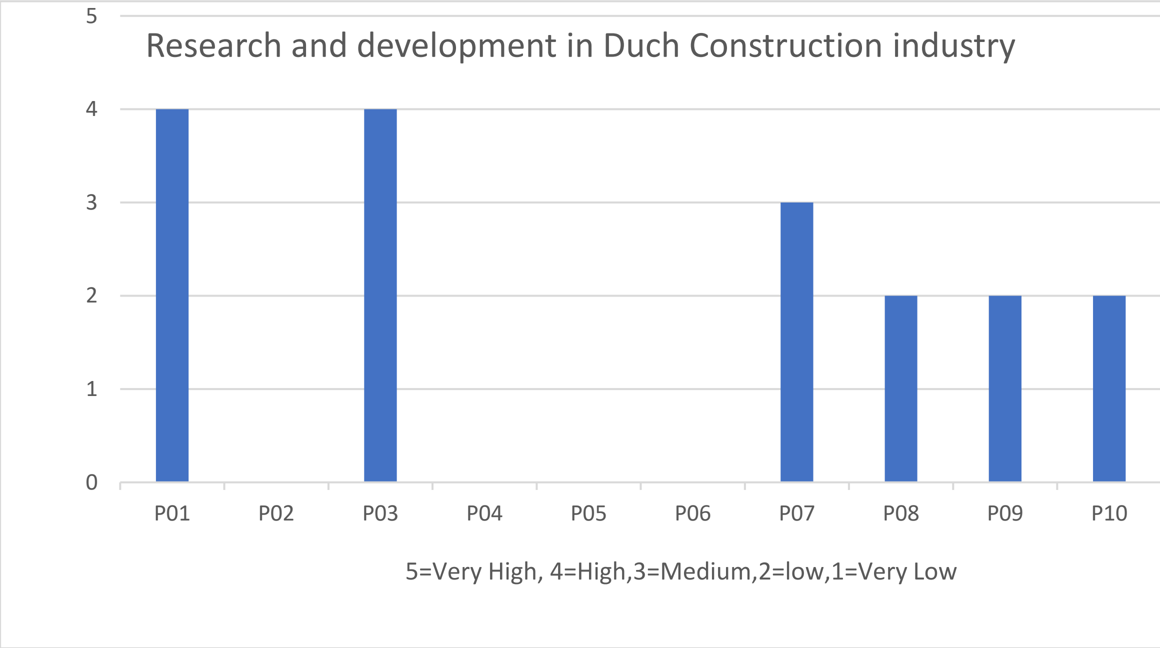

Figure 4- Research and development in the Dutch concrete industry

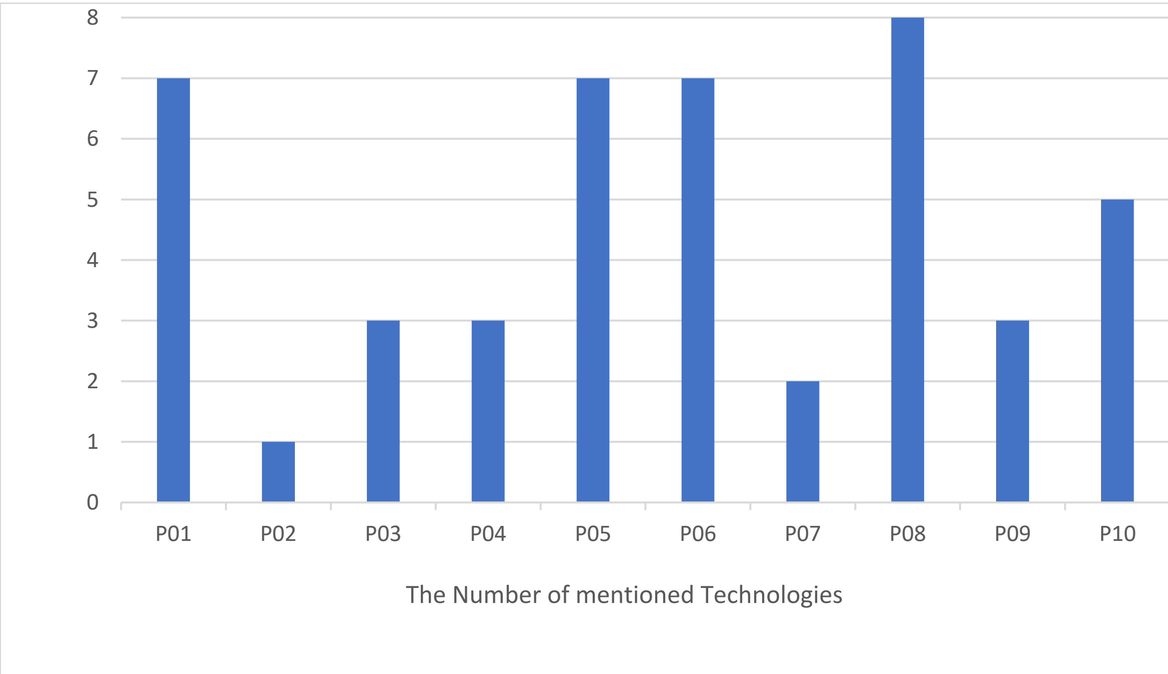

Figure 5- The number of mentioned technologies

Lastly, the third question inquired about the participants' expectations regarding the amount of funding allocated for the advancement of knowledge and research on sustainable concrete.

3. Do you consider that there is enough funding allocated to SC research and development in the Netherlands?

The corresponding results are presented in Figure 6 which shows the three ranges of not enough, neutral, and enough noted by the participants.

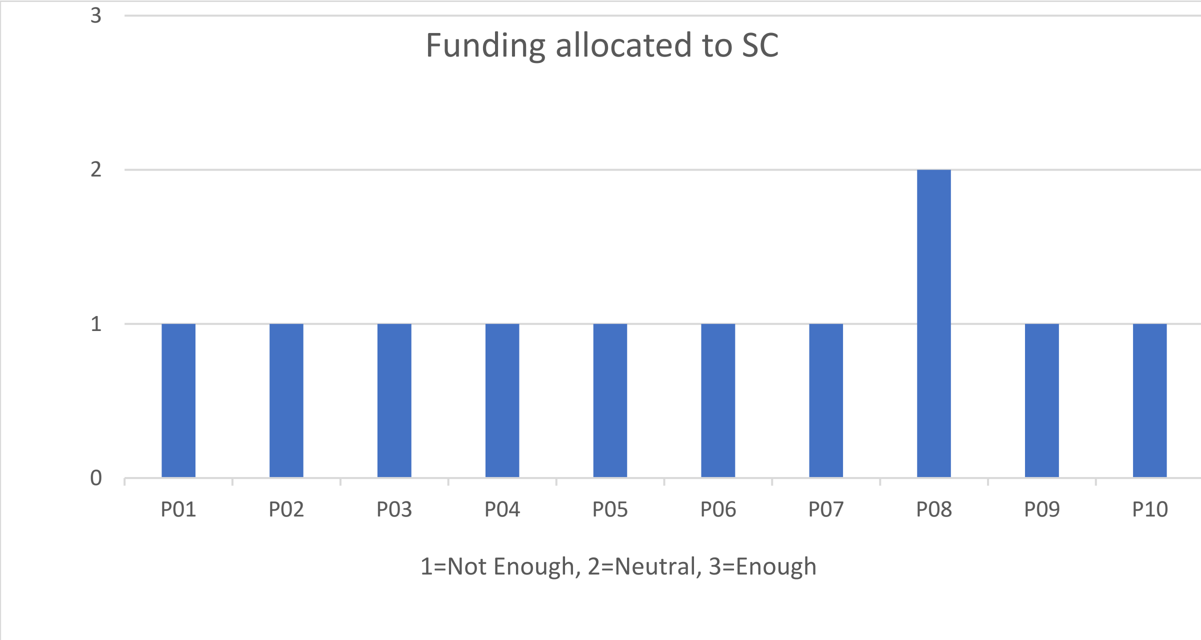

Figure 6- Expected allocated funding in SC

Function 2- Entrepreneurial Experiment

Entrepreneurial Experimentation is crucial for the practical implementation of sustainable concrete. It involves pilot projects and real-world demonstrations to test viability and performance. Alternative materials and innovative techniques are explored for reduced environmental impact. Success is measured by implemented projects, carbon emission reductions, and cost savings. This function drives the adoption of sustainable concrete. Participants' experiences with sustainable concrete projects were assessed by asking two questions to understand the challenges faced and consideration of environmental concerns. In the following, their answers were reported.

4. Have you ever been part of a project that used SC? If so, what were the main challenges faced during the project?

By gathering responses to this question, it is possible to determine whether the participants had prior experience with a real-world project and what challenges they encountered. Table 6 summarizes the participants' experiences with projects including SC and the main challenges they encountered. This gives me insights into how SC is used in real-world situations.

Table 6- Mentioned challenges during projects

respectively	Challenges						
	Not Enough regulation	Perception of Quality	cost	Resistance to Change	Lack of Awareness	Technical	Government support
P01	1	1	1	1	-	-	-
P02	-	-	-	1	1	-	-
P03	-	-	-	-	-	1	-
P04	-	1	1	1	-	-	1
P05	-	-	-	-	1	1	-
P06	-	1	1	1	-	-	-
P07	1	1	1	-	-	-	-
P08	1	-	-	1	-	-	-
P09	-	-	-	-	-	1	-
P10	-	-	-	-	-	-	-
Total times mentioned	3	4	4	5	2	3	1

5. To what extent environmental concerns are considered when implementing SC in a project?

Table 7 shows what participants think about considering environmental concerns when using SC in projects. By looking at their answers, I can understand how much importance they give to environmental factors in SC implementation. The answer appears in the table if their response contains a range according to their opinions on the importance. However, there is a "not mentioned directly" option for replies that do not indicate any predicted amount of relevance in the table.

Table 6 and Table 7 provide a clear overview of participants' experiences, challenges, and environmental considerations in sustainable concrete. These tables are helpful tools for gaining deeper insights into entrepreneurial experimentation.

Table 7- Environmental Concerns in practical projects

P01	High
P02	High
P03	Not mentioned directly
P04	Very High
P05	High
P06	Not mentioned directly
P07	High
P08	High
P09	Not mentioned directly
P10	High

Function 3- Market Formation

Market Formation establishes a market for sustainable concrete by partnering with industry and government to promote green building practices. Progress is measured by the availability of sustainable concrete products, market share, and partnerships formed. By creating strong market demand, this function drives the adoption of eco-friendly construction. Insights into market formation were gathered through the following questions:

6. Is the material for SC easily accessible and is there enough availability for entire construction projects?

Many requests for sustainable concrete are unavoidable because there may be many projects that require concrete. This request raises questions about whether the SC will be available for all the building projects. The participant's replies to the query concerning what they were taught regarding the accessibility of the material are shown in Table 8.

Table 8- Accessible Sustainable Concrete Materials

P01	long term availability will be an issue/ few suppliers / the availability of SC is now not enough for big projects.
P02	Yes
P03	no clear answer is possible
P04	(No obvious answer)
P05	large availability
P06	This is no issue.
P07	This is one of the main challenges
P08	(No obvious answer)
P09	Yes
P10	I don't think so.

7. In your opinion, is the initial higher cost of using SC seen as an investment by the customers?

More technology and novel materials are required to make concrete more sustainable. As a result, making sustainable concrete has a greater initial cost, which may be thought of as an investment. Table 9 presents the participant's expectations about cost perception.

Table 9- Cost perception

P01	With higher costs, there is no incentive for producers/suppliers to invest.
P02	Higher cost
P03	Expensive
P04	Yes, clients see it as an investment,
P05	If anyone needs a building it needs materials design and assembly he would be paying the bills and also the SC solution.
P06	Cost will initially be higher. It is not so much as an investment
P07	Higher implementation cost.
P08	No.
P09	No, but of course we want to.
P10	I don't think so.

8. Do you think that the availability of SC can continue meeting the growing demand in construction projects?

The demand for SC may increase when construction activity picks up since more concrete will be required for use in building construction. The future supply of the material raises certain concerns in considering the increasing demand. Table 10 shows the participant's reactions to the sense of rising availability demand.

Table 10-Growing Demand Availability Perception

P01	Neutral.
P02	Irrelevant.
P03	Yes.
P04	Yes of course.
P05	Yes.
P06	Availability will follow demand.
P07	No.
P08	I don't know.
P09	Yes.
P10	I have no idea, is there a growing demand for SC.

Function 4- Creation of societal demand

To better understand the social demand for sustainable concrete, I wanted to know how reliable the material is, especially when used over a long period of time. So, I asked the following question:

9. Do you think SC is a reliable material for long-term construction? SC construction, depending on the people we are asking, can be changed.

In general, conventional concrete is a dependable material that has been in use for more than one hundred years. A long-term, dependable availability should result from the switch to sustainable concrete. Table 11 presents the answers provided by specialists in response to the long-term reliability of sustainable concrete.

Table 11- Sustainable concrete reliability

P01	Need to be proven and of course, some innovative materials will fail.
P02	Sure.
P03	Yes, if tested, monitored, and eventually adjusted well.
P04	Yes of course.
P05	Yes.
P06	It absolutely is.
P07	Yes.
P08	Yes.
P09	Yes, it should be.
P10	I don’t know if one could say that it is a reliable material for long-term construction – period.

Table 12 displays the responses related to the number of client orders for sustainable concrete, which were gathered to gain insights into society's perspective on the material by asking the following question:

10. In the circumstances where you have clients, what is the approximate percentage of clients who order Sustainable Concrete (SC) for their structures? Additionally, if possible, what is the volume associated with these orders?

Table 12- Amount of client orders

P01	10%. The overall volume is not even 1%.
P02	Very new, so only the early adopters.
P03	N.A. (working at research institute).
P04	15%
P05	100%
P06	Hardly any client would do that.
P07	Applied in very small amounts in pilot projects.
P08	<1%

P09	I think that's one of the main problems on this moment that clients first part doesn't want to pay more for durable, sustainable concrete
P10	We are a client; I don't think we order SC.

Function 5- Shaping of Technology Trajectories

This section of the report focuses on the "Shaping of Technology Trajectories". Two key questions were asked to gather insights into the influence of regulations and policies on the transition to SC.

11. Are you aware of any regulations or policies that are hindering the transition to the use of SC/Sustainable Construction?
12. Are you aware of the regulations that support the use of SC?

Question 11 explores the awareness of any regulations or policies that hinder the adoption of SC, while question 12 investigates the participants' knowledge of regulations supporting the use of SC. Government policies and regulations incentivize the development and adoption of sustainable concrete production methods, including subsidies, tax incentives, and regulations on emissions and building codes. By understanding the participants' awareness of these regulations, I can assess their impact on shaping the trajectory of SC technology adoption.

Table 13- Regulations Hindering the SC Adoption

P01	Yes, No performance-based rules or codes for (sustainable) concrete.
P02	Maybe the lack of it. Currently, too many of the steps we need to make are voluntary and not mandatory.
P03	Regulations are not the problem.
P04	Yes, there is not yet a standard for products.
P05	Not in any regulations or codes but more in the lack of knowledge of people involved in the project.
P06	There are many. Alle concrete codes are based on the use of cement sand and aggregate. For example, EN 206 and EN 197. New codes that describe the performance of concrete are needed.
P07	The design code Eurocode 2 is based on the application of concrete according to EN 206, with cement according to EN 197. Any deviation from the mixtures allowed in these codes means that Eurocode 2 is not readily applicable and elaborate evidence needs to be produced to show equivalent performance.

P08	Yes.
P09	The standards. Not all, but we want to have also the constructional safety of buildings and roads, etcetera, etcetera.
P10	I believe that international standards indicate that concrete should contain cement, which would hinder alternatives without cement if true.

Table 14- Regulation Supporting SC

P01	General MPG (Milieuprestatie gebouw) for non-residence buildings now, but not specific for concrete. For the civil market, there are no general regulations. Only Rijkswaterstaat has its own regulations for SC.
P02	Regulations in general: Yes. Mandatory steps to make: No.
P03	No.
P04	Pantheon Performance Protocol of SustCon.
P05	Regulation will come after the first steps or largely implications of the solution. Making regulations on niche solutions is not efficient.
P06	There are a few CUR/CROW guidelines in the Netherlands for the use of crushed concrete (CUR 127) and the use of hardening after 180 days (CUR 122). The use of bottom ash in concrete is in CUR 116 and CUR 128. There is a FIB bulletin about alternative rebar. And there are international several guidelines.
P07	Rijkswaterstaat RTD 1033 and RTD 1034, CUR-recommendation 48, BRL2508
P08	Yes.
P09	No.
P10	No.

Function 6- Building of Innovation Networks

In the "Building of Innovation Networks" function of the TIS framework, this report section focuses on the collaborations between industry, academia, and government to promote innovation and knowledge sharing in sustainable concrete (SC) technologies. To assess these collaborations, question 13 was asked to determine the participants' involvement and the specific outcomes achieved.

13. Are you part of collaborations between industry, academia, and government to promote innovation and knowledge sharing in SC technologies, and what specific outcomes were achieved because of these collaborations?

Analyzing the participants' engagement and the resulting outcomes offers valuable insights into the effectiveness of building innovation networks within the TIS framework for advancing SC technology.

Table 15- Participating in collaborations and mentioned outcomes

P01	We do participate in "het Betonakkoord". "Betoninnovatie loket" "proeftuin" (experimental environment)
P02	yes
P03	Start nieuwe proeftuinen - presentaties info bijeenkomsten - Bouwcirculair , Development & testing of alternative binders
P04	Yes, we (BouwCirculair.nl) organize living labs to stimulate innovation. This is now being done for reinforced polymer concrete. This living lab is supported by Rijkswaterstaat, TNO and SKG-IKOB.
P05	I was part of the FIB TG steel fibers.
P06	I work together with several parties. We used selfhealing concrete / basalt re-inforcement / alakli activated cement / geopolymer concrete / several second-ary materials / etc. Some in prototypes and some in production.
P07	Participation in working groups in the Betonakkoord: - Formation of roadmap 'dalende MKI' - Formation of the 'betoninnovatieloket' - Sharing knowledge (Duurzame betonconstructies - Betonakkoord) Lecturer at Betonvereniging of a course on calculating and designing with MKI-values in concrete structures Co-author of Stufib-report 24
P08	Yes
P09	That's the Beton akkoord.
P10	I am not, some of my colleagues are.

Function 7- Fostering of Sociotechnical Acceptance

In this report section, I focus on the "Fostering of Sociotechnical Acceptance" function within the TIS framework, specifically regarding sustainable concrete (SC) technologies in the Dutch construction industry. Question 14 investigates the strategies employed to engage stakeholders and the public in the development and implementation of SC technologies, aiming to ensure sociotechnical acceptance.

14. What strategies have been used in the Dutch construction industry to engage stake-holders and the public in the development and implementation of SC technologies, and what are the main achievements of such strategies?

Table 16- Collaborations

P01	“het Betonakkoord” is the (only) initiative. A roadmap for SC has been developed.
P02	Innovations like sensoring and talking assets
P03	-
P04	- living labs - set minimum sustainable requirements (MKI) for products - calling on governments to comply with the climate law - Betonakkoord
P05	The bouwend Nederland (Dutch construction industry) is funding large part of the CROW. CROW is instituted for development of SC technologies.
P06	There are several seminars etc. where sustainable concrete is discussed.
P07	Raising awareness of the impact of the construction industry on carbon emissions, implementing award criteria in contracts for reduction of environmental impact, formation of the ‘betonakkoord’ which creates a level playing field for all parties involved.
P08	Chain cooperation, resulting from the concrete agreement. And especially stimulating in buyers' groups. So far, not so successful. In practice, all other things known to me are limited to demo projects.
P09	Yeah, sharing and sharing and knowledge. We do it, for example, by our website. We tell it our members, we did some webinars last year or in 2021.
P10	I don’t know.

Furthermore, Question 15 explores the possible reasons for stakeholders and customers resisting the implementation of SC practices, providing valuable insights into the challenges and concerns that need to be addressed.

15. What are the possible reasons for stakeholders and customers to resist the implementation of SC practices?

Understanding these factors is crucial for fostering wider acceptance and adoption of sustainable concrete practices in the construction industry.

Table 17- Resist to implementation

P01	Higher costs, Not the core business of the cement industry.
P02	Lack of knowledge, lack of urgency, lack of funds, lack of stimulation
P03	-
P04	- convince all stakeholders of the importance - reduce costs - identify the risks - get a picture of the actual environmental impact - take the authority with you so that it can be approved - communication about the results that all parties value - don't stop at 1 project, but scale up
P05	Time, money, safety, quality, buildability, and sustainability.
P06	Habit/cost / codes/guaranties / fear of change
P07	Cost, risk of implementing unproven technologies
P08	Too expensive, unknown, no urgency.
P09	I think maybe the pricing of it.
P10	Mainly vested interests and uncertainty about (long-term) performance, I suppose.

After collecting information from specialists in the concrete sector, the next chapter of my research analyzes their answers to uncover the factors that drive and barrier of sustainable concrete in the construction industry in the Netherlands. By carefully studying their responses, I can gain valuable insights into what motivates and holds back the adoption of sustainable concrete practices in the industry. This analysis aims to provide a clear understanding of the main reasons that influence the implementation of sustainable concrete technologies in the construction sector of the Netherlands.

6. CHAPTER 5: DISCUSSION

6.1 General questions

The actor section of the TIS dimension reveals the involvement of multiple stakeholders in the concrete sector of the Dutch construction industry. To ensure a comprehensive understanding, a diverse range of viewpoints was sought in this study. Interviews were conducted with individuals who possess specialized knowledge and extensive experience in the field of concrete within the Netherlands, as highlighted in Table *5*.

The participants selected for the interviews represent various job titles and areas of expertise, collectively providing a well-rounded perspective on the subject matter. Their extensive experience in concrete technology, sustainability, infrastructure, asset management, and engineering adds credibility to the insights gathered from their responses.

Table 5 presented the general information about the participants, including their job titles, years of experience, and areas of expertise. The combined experience of the participants highlights the wealth of knowledge and expertise available within the group.

The inclusion of participants with diverse backgrounds and expertise ensures a comprehensive and well-informed analysis of the factors influencing the concrete sector in the Dutch construction industry. The insights derived from their responses will contribute to a more robust understanding of the challenges, opportunities, and potential strategies for the advancement of sustainable concrete technologies within the sector.

6.2 Specialized questions

6.2.1 Function 1-Knowledge Development

The function of "Knowledge Development" within the Technological Innovation Systems (TIS) framework plays a pivotal role in shaping the trajectory of sustainable concrete (SC) technologies. This function's significance stems from its ability to illuminate participants' perspectives and insights, providing a solid foundation for informed decision-making and strategic planning. By capturing participants' definitions of SC, their expectations for research and development, their awareness of sustainable concrete methods, and their perceptions of funding allocation, this function offers a panoramic view of the current state of knowledge and awareness within the Dutch construction industry. The depth of understanding achieved through these responses empowers researchers and stakeholders to assess existing gaps, identify potential barriers, and uncover opportunities for the advancement of sustainable concrete technologies. This function's outputs transcend mere data collection, serving as a compass guiding the formulation of effective policies, targeted investments, and collaborative efforts aimed at propelling sustainable concrete innovation forward.

To gain a clearer understanding of the participants' perspectives on the "Knowledge Development" component within the TIS framework, I presented them with three specific questions. The subsequent section provides an overview of their responses.

Question 1 aimed to capture participants' definitions of Sustainable Concrete (SC) from their viewpoints. It was important to ensure that their definitions aligned with the research objectives. Fortunately, all participants provided definitions that were consistent with the research focus, emphasizing the inclusion of environmental considerations. The quality of their definitions is depicted in Figure 3, which showcases the alignment with the research goals.

The second question aimed to uncover participants' expectations related to research and development in the Dutch construction industry concerning SC. Additionally, I assessed their understanding of various methods to enhance concrete sustainability. The responses are visualized in Figure 4, providing a graphical representation of their knowledge and expectations. It's worth noting that six participants offered direct responses, three of them indicating high or medium expectations while three mentioned low which shows different opinions of participants. For half of the valid answers, this can be a driver while it is a barrier for others.

Additionally, participants were asked to share specific examples of SC technologies they were familiar with, further highlighting their knowledge and awareness. Figure 4- Research and development in the Dutch concrete industry

presents the number of mentioned technologies, providing an overview of the range of SC technologies recognized by the participants which illustrates the high number of available ways to make concrete more sustainable. Most participants listed more than three techniques, indicating a comprehensive understanding of the topic.

Finally, I explored participants' views on the allocation of funding for SC research and development within the Netherlands. Their responses are illustrated in Figure 6, providing insight into their thoughts on the necessary funding required to bolster research and further knowledge in sustainable concrete. It is of interest to note that nine out of ten participants stated that the current funding allocated for research is insufficient, highlighting a substantial barrier within this sector.

The information collected deepens my understanding of the participants' perspectives on knowledge development in the context of sustainable concrete. This data is valuable in assessing the current state of research and development, identifying potential gaps, and seeking opportunities for further advancements in sustainable concrete technologies.

6.2.2 Function 2- Entrepreneurial Experiment

The "Entrepreneurial Experiment" function in the TIS framework holds a vital role in testing the practical feasibility of sustainable concrete (SC) technologies. By revealing challenges faced during SC projects, this function uncovers the complexities of integrating SC in real-world construction within the TIS framework. Challenges, such as regulatory gaps, quality perceptions, costs, resistance to change, awareness gaps, technical issues, and limited government support, highlight hurdles to SC adoption. Frequent mentions of resistance to change and costs indicate potential barriers. This function's insights aid in understanding practical challenges, assessing participants' adaptability and directing policy efforts for smoother SC integration. It offers a dynamic understanding of innovation's real-world challenges, guiding a strategic path for advancing sustainable concrete.

Table 6 provides an overview of the challenges mentioned by the participants during their projects involving SC. The challenges mentioned include not enough regulation, perception of quality, cost, resistance to change, lack of awareness, technical difficulties, and lack of government support. These challenges highlight the complex nature of integrating sustainable concrete into real-world projects within the TIS framework. The high number of times the challenges of resistance to change and cost were mentioned suggests that there may be barriers related to the adoption of sustainable practices and the financial considerations associated with implementing SC.

The participants' responses offer valuable insights into the difficulties faced during the construction process when using SC within the TIS framework. These insights are crucial for assessing the participants' practical knowledge and their ability to find solutions when confronted with challenges. Moreover, the challenges identified provide valuable information for policymakers and stakeholders involved in the TIS framework, as they indicate areas where further support, such as regulatory frameworks or government initiatives, may be needed to facilitate the adoption of sustainable concrete in construction projects.

In Table 7 participants were asked about the extent to which environmental concerns were considered when implementing SC in their projects. Most of the participants indicated a high level of consideration for environmental factors. This is encouraging and demonstrates a positive trend within the TIS framework, where stakeholders increasingly recognize the importance of integrating environmental concerns into the implementation of SC as a significant driver. However, the fact that a couple of participants did not directly mention environmental concerns suggests that there is a need for further education and awareness regarding the environmental benefits of SC within the TIS framework.

6.2.3 Function 3- Market Formation

The "Market Formation" function within the TIS framework is crucial for understanding how sustainable concrete (SC) is taking shape in the Dutch construction industry. By asking specific questions about accessibility, cost perception, and availability of SC materials, this function provides insights into how SC is being received in the market. These insights help us see the challenges and possibilities of SC's growth. Exploring questions about material availability, customer perceptions of costs, and SC's ability to meet demand gives us a clear view of how SC is fitting into the market. The information gathered from participants' answers guides policymakers, industry players, and researchers in making informed decisions about SC's future. It offers a detailed understanding of the factors affecting the market and helps in planning strategies for a more sustainable and accessible SC in construction.

The market formation of sustainable concrete (SC) within the construction industry in the Netherlands was explored through three specific questions, aiming to gain insights into the accessibility, cost perception, and availability of SC materials. The participants' responses, as summarized in Tables 8, 9, and 10, shed light on these aspects and provide valuable perspectives on the market dynamics surrounding SC.

Question 6 focused on the accessibility and availability of SC materials for entire construction projects. The responses varied, with participants expressing concerns about long-term availability and limited suppliers. Some participants highlighted the current insufficiency of SC availability for large projects, while others mentioned the existence of a large availability. This indicates a mixed scenario regarding the accessibility and availability of SC materials, with potential challenges and variations depending on the project requirements and suppliers' capacity.

Question 7 delved into the perception of customers regarding the initial higher cost of using SC. The participants' answers reflected a range of viewpoints. While some participants expressed that higher costs discourage producers and suppliers from investing, others acknowledged that customers perceive the higher cost as an investment. The cost perception of SC varied among participants, highlighting the need for further examination of the economic implications and incentives associated with its adoption. However, higher initial costs as mentioned by most of the participants can be barriers to using SC.

Question 8 addressed the participants' perspective on whether the availability of SC can meet the growing demand in construction projects. The responses were diverse, with some participants expressing confidence in the availability aligning with demand, while others believed it would not. There were also participants who considered the question irrelevant or expressed uncertainty about the availability's ability to meet the growing demand. Overall, most of the participants believed that the concrete sector in the Netherlands could be relied on for higher future demands which is a positive sign for adaptation. This highlights the importance of assessing the scalability and capacity of SC production to cater to increasing demand in the construction industry.

6.2.4 Function 4- Creation of societal demand

Understanding the desire for sustainable concrete (SC) holds great significance. This function sheds light on the extent of interest and demand for SC within society. It examines people's trust in SC's durability for long-term construction and the frequency of SC usage by clients. The resultant insights provide valuable perspectives on societal perceptions and the incorporation of SC in construction practices.

To gain insights into the social demand for sustainable concrete (SC), two questions were posed, focusing on the reliability of SC for long-term construction and the percentage of clients ordering SC for their structures. The participants' responses, as summarized in Tables 11 and 12, provide valuable perspectives on the social perceptions and adoption of SC.

Question 9 aimed to assess the participant’s opinion on the reliability of SC as a material for long-term construction. The responses indicate a generally positive outlook, with participants expressing confidence in the reliability of SC when certain conditions are met. Some participants emphasized the importance of testing, monitoring, and potential adjustments to ensure the long-term reliability of SC. It is worth noting that one participant mentioned the need for innovative materials to undergo rigorous testing and acknowledged that not all may prove to be reliable. These responses highlight the cautious optimism surrounding the reliability of SC and the need for thorough evaluation and validation processes.

Question 10 sought to understand the extent of client orders for SC and the associated volume of those orders. The responses varied significantly, reflecting different levels of adoption and market penetration. Some participants mentioned low percentages, such as 10%, 15%, or less than 1%, indicating a relatively limited demand for SC among clients. One mentioned a higher percentage of 100% suggesting a greater acceptance and adoption of SC by a portion of the client base. There were also participants who mentioned that SC is still in the early stages of adoption, with only a few early adopters incorporating it into their projects. These responses underscore the diversity in the current level of demand for SC within the construction industry and the potential for further growth and market development.

Tables 11 and 12 provide an overview of the participants' perspectives on the reliability of SC and the percentage of clients ordering SC for their structures. These insights offer valuable information for understanding the social demand and acceptance of sustainable concrete. It can be concluded that while there is a positive perception of SC's reliability, levels of client orders are not high as can be expected. It can be suggested for an evolving landscape further research, testing, and market education may be required to enhance the social demand for SC and its wider adoption in construction projects.

6.2.5 Function 5- Shaping of Technology Trajectories

In the context of advancing sustainable concrete (SC) and sustainable construction, the role of regulations and policies cannot be underestimated. Function 5, "Shaping of Technology Trajectories," casts a spotlight on the regulatory landscape's influence on the transition to SC. By examining the regulations' impact on SC adoption and awareness, this function offers a critical understanding of how policy frameworks shape the trajectory of SC's integration. It delves into potential hurdles posed by regulations and highlights avenues for fostering a more supportive environment for SC within the construction sector.

The "Shaping of Technology Trajectories" section of the report focuses on regulations and policies that influence the transition to sustainable concrete (SC) and sustainable construction. Two key questions were asked to gather insights into the impact of regulations on SC adoption: whether participants are aware of any regulations or policies hindering the transition to SC and whether they are aware of regulations supporting the use of SC. The participants' responses, as summarized in Tables 13 and 14, provide valuable insights into the regulatory landscape and its influence on shaping the trajectory of SC adoption.

Question 11 aimed to explore participants' awareness of regulations or policies hindering the adoption of SC. The responses indicate various regulatory challenges that may impede the transition to SC. Some participants mentioned the lack of performance-based rules or codes specifically for sustainable concrete, while others highlighted the absence of standards for SC products which can be noticed as a significant barrier. A participant also noted the need for new codes that describe the performance of concrete, suggesting that the current regulations may not adequately accommodate sustainable concrete practices. These responses underscore the importance of regulatory frameworks that explicitly address sustainable concrete and support its adoption, providing clarity and guidance for industry stakeholders.

Question 12 sought to assess participants' knowledge of regulations supporting the use of SC. The responses indicate a mix of awareness and a lack of specific regulations. Some participants mentioned general regulations that encompass sustainability considerations but may not have specific requirements for concrete. One participant highlighted the Pantheon Performance Protocol of SustCon as a regulation supporting SC. Other participants noted the presence of guidelines and recommendations related to the use of specific sustainable practices or materials in concrete construction. These responses suggest that while there may be some regulations and guidelines supporting SC, there may still be a need for comprehensive and concrete-specific regulatory frameworks to fully support and facilitate the adoption of sustainable concrete practices.

Tables 13 and 14 provided an overview of the participants' perspectives on regulations hindering and supporting the adoption of SC. These insights help me understand the influence of regulations on shaping the trajectory of SC technology adoption. The responses indicate the need for more specific regulations and standards that address sustainable concrete, its performance, and its environmental impact. Clear and supportive regulations can incentivize the development and adoption of SC by providing a regulatory framework that encourages innovation, ensures quality and performance standards, and facilitates market acceptance.

6.2.6 Function 6- Building of Innovation Networks

The Building of Innovation Networks function focuses on teamwork between businesses, educational institutions, and the government to come up with new ideas and share knowledge about SC. By looking at how much people are involved and what comes out of these partnerships, we get really important information about how well these innovation networks are working. This helps us understand how to make SC technology even better in the future.

The "Building of Innovation Networks" section of the report focuses on collaborations between industry, academia, and government in promoting innovation and knowledge sharing in sustainable concrete (SC) technologies. Question 13 aimed to assess the participants' involvement in such collaborations and the specific outcomes achieved as a result. Analyzing their engagement and the mentioned outcomes provides valuable insights into the effectiveness of building innovation networks within the Technological Innovation System (TIS) framework for advancing SC technology.

The responses, as summarized in Table 15, indicate that several participants are actively involved in collaborations between industry, academia, and government to promote innovation and knowledge sharing in SC technologies. These collaborations take various forms, such as participation in initiatives like "het Betonakkoord" and "BouwCirculair," as well as involvement in working groups and living labs. Participants also mentioned specific outcomes achieved through these collaborations, which highlight the positive impacts of these networks.

Some of the outcomes mentioned include the development and testing of alternative binders, the organization of living labs to stimulate innovation in reinforced polymer concrete, and participation in working groups to form roadmaps and share knowledge on sustainable concrete construction. These outcomes demonstrate the tangible results of collaboration, such as the advancement of innovative materials and technologies, the formulation of strategic roadmaps, and the dissemination of knowledge within the industry.

The participants' engagement in these collaborations and the resulting outcomes indicate the effectiveness of building innovation networks in the context of SC technologies. Collaborations between industry, academia, and government provide a platform for knowledge exchange, research and development, and the co-creation of solutions. By bringing together different stakeholders, these networks foster innovation, facilitate the transfer of expertise, and accelerate the adoption and diffusion of sustainable concrete practices.

Table 15 provided an overview of the participant’s involvement in collaborations and the outcomes achieved. These insights highlight the importance of establishing and nurturing strong innovation networks within the TIS framework for sustainable concrete. These available collaborations between industry, academia, and government create a positive effect for cooperation, synergy, and collective efforts toward advancing SC technologies and addressing sustainability challenges in the construction industry.

6.2.7 Function 7- Fostering of Sociotechnical Acceptance

Function 7, "Fostering of Sociotechnical Acceptance," assumes a pivotal role within the Technological Innovation System (TIS) framework, particularly concerning sustainable concrete (SC) technologies in the Dutch construction industry. This function dives into the strategies employed to engage stakeholders and the public in the development and use of SC technologies. Additionally, it investigates why some stakeholders and customers resist using SC practices. By unraveling these aspects, this function offers essential insights for promoting wider acceptance and incorporation of sustainable concrete approaches in the construction sector.

This report section focuses on the "Fostering of Sociotechnical Acceptance" function within the Technological Innovation System (TIS) framework, specifically in relation to sustainable concrete (SC) technologies in the Dutch construction industry. Question 14 aims to explore the strategies employed in the industry to engage stakeholders and the public in the development and implementation of SC technologies, as well as the main achievements of these strategies. Additionally, Question 15 investigated the possible reasons for stakeholders and customers resisting the implementation of SC practices. Understanding these factors is crucial for fostering wider acceptance and adoption of sustainable concrete practices in the construction industry.

Table 16 provided insights into the strategies used in the Dutch construction industry to engage stakeholders and the public in the development and implementation of SC technologies. Some of the mentioned strategies include:

"het Betonakkoord": This initiative serves as a platform for collaboration and has led to the development of a roadmap for sustainable concrete. Funding and support from organizations like Bouwend Nederland and CROW: These organizations play a role in the development and promotion of sustainable concrete technologies.

These strategies have achieved several notable accomplishments, such as the development of a roadmap for SC, the advancement of innovative technologies talking assets, and the funding of initiatives focused on SC technology development.

Table 17 focused on the possible reasons for stakeholders and customers resisting the implementation of SC practices. The responses highlight various factors, including:

Higher costs: The increased expenses associated with implementing SC practices can be a deterrent.

Lack of knowledge, urgency, and funds: Limited awareness and understanding, along with a lack of perceived urgency and financial resources, hinder the acceptance and adoption of SC technologies.

Risk aversion: Concerns about the reliability and effectiveness of unproven technologies can lead to resistance.

Resistance to change: Habits, established codes, guarantees, and fear of change can impede the adoption of SC practices.

Cost considerations: The perception that SC practices are expensive and lack immediate urgency may discourage stakeholders.

Uncertainty and lack of awareness: Limited knowledge about the environmental impact and benefits of SC technologies can contribute to resistance.

These insights into the possible reasons for resistance provide valuable information for addressing challenges and concerns in the adoption of SC practices. By addressing issues such as cost, risk perception, knowledge gaps, and resistance to change, stakeholders can work towards fostering greater acceptance and implementation of sustainable concrete technologies.

Overall, the information gathered through Questions 14 and 15 sheds light on the strategies employed to engage stakeholders and the public in the development and implementation of SC technologies, as well as the factors contributing to resistance. By understanding these dynamics, efforts can be focused on addressing barriers, raising awareness, promoting knowledge sharing, and providing incentives to foster wider acceptance and adoption of sustainable concrete practices in the Dutch construction industry.

7. CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusion

This research aimed to propose policies that could accelerate the transition towards a more sustainable building industry in the Netherlands. To achieve the goal, I first identified the level of adaptation for sustainable concrete and second by answering the first sub-question of the thesis, then I identified and analyzed the drivers and barriers that can influence construction companies to transition toward sustainable concrete which was the answer to the second sub question`. Finally, I propose some recommendations in this chapter as the answer to the last sub-question.

As a result of the first sub-question, it can be concluded that the transition toward sustainable concrete production has shown progress, but also challenges. The good news is that emissions have gone down by half since 2017, which is a great start. But there is still more work to do to reach the future goals. It is important for everyone involved to work together more closely, share what they know, and come up with new ideas. To address what can be more beneficial and what can slow down that progress, I move forward to the second sub-question.

Through this study, I have gained valuable insights into the drivers and barriers that affect Dutch construction companies in implementing sustainable concrete (SC). By examining the different functions of the Technological Innovation System (TIS) framework, I have explored various aspects related to knowledge development, entrepreneurial experiment, market formation, creation of societal demand, shaping of technology trajectories, the building of innovation networks, and fostering of sociotechnical acceptance. Based on the responses provided by the participants, I can draw several conclusions.

In terms of knowledge development, participants demonstrated a clear understanding of sustainable concrete, emphasizing its environmental considerations. However, there is a need for increased funding to support research and development in the Dutch construction industry, as participants highlighted the current insufficiency of funding for SC research.

The entrepreneurial experiment revealed challenges, encompassing resistance to change, cost considerations, and lack of awareness. Notably, the deficiency in awareness within the Dutch construction industry pertains to customers, not specialists a contrast to the findings drawn by Alsanad in 2015, which centered around this knowledge gap prevailing among various individuals in the same industry. These barriers must be addressed to facilitate the adoption of sustainable concrete in real-world projects. It is crucial to establish supportive regulatory frameworks and government initiatives to overcome these challenges.

Market formation for sustainable concrete in the Netherlands exhibits a mixed scenario in terms of accessibility and availability of SC materials. Long-term availability and limited suppliers were mentioned as concerns. Additionally, the perception of higher costs associated with SC implementation can act as a barrier. Ensuring a reliable and scalable supply chain of SC materials is essential to meet the growing demand in the construction industry. This emphasizes a difference between the Dutch construction industry and the other countries studied by Altarrazi et al. in 2022, where there were issues with having a dependable supply chain over the long term.

The creation of societal demand for sustainable concrete requires further education and awareness. While participants expressed confidence in the reliability of SC, the percentage of clients ordering SC for their structures varied significantly. This suggests the need for more research, testing, and market education to enhance social demand and promote wider adoption of sustainable concrete.

Regulations and policies play a significant role in shaping the trajectory of SC adoption. Participants identified the lack of specific regulations and standards for sustainable concrete as a hindrance. Clear and supportive regulations are needed to incentivize the development, adoption, and diffusion of SC technologies.

Building innovation networks between industry, academia, and government have proven effective in advancing SC technologies. Collaborations and knowledge sharing through initiatives like "het Betonakkoord" and involvement in working groups and living labs have resulted in the development of innovative materials, strategic roadmaps, and the dissemination of knowledge. These networks should be further nurtured and expanded to accelerate the adoption of sustainable concrete. This clarifies an apparent distinction between the Dutch construction industry, where sectoral collaboration is a driver, and other countries, where collaboration might be a barrier, as highlighted by de Brito & Kurda 2021 and Altarrazi et al 2022.

Fostering sociotechnical acceptance requires strategies to engage stakeholders and the public. The industry has employed various strategies, including collaboration platforms, funding support, and initiatives, such as "het Betonakkoord." However, higher costs, lack of knowledge, resistance to change, and uncertainty remain as barriers to wider acceptance. Efforts should be focused on addressing these challenges through awareness campaigns, knowledge dissemination, and providing incentives for adopting sustainable concrete practices.

7.2 Recommendations

Based on the findings of this study and as an answer to the third sub-question of the thesis, several recommendations can be made to accelerate the transition to a more sustainable building industry.

Overcome barriers:

Increase funding for research and development: Based on the discussed result of the knowledge development function, the Dutch government and industry stakeholders should allocate more financial resources to support research and development in sustainable concrete technologies. Adequate funding is crucial to drive innovation and address the challenges associated with implementing SC in real-world projects.

Strengthen testing and validation processes: Discussion about market formation and creation of social demand elaborates that robust testing and validation processes should be established to ensure the reliability and long-term performance of sustainable concrete materials. This will enhance confidence in SC technologies and provide assurance to stakeholders regarding their suitability for construction projects.

Develop comprehensive regulations and standards: By considering the result of shaping technology trajectories function it can be recommended that regulatory frameworks specific to sustainable concrete should be developed to provide clarity and guidance to industry stakeholders. Performance-based rules, codes, and standards that explicitly address sustainable concrete and its environmental impact should be established to support its adoption.

Promote awareness and education: Building Innovation networks function showed that awareness campaigns and educational initiatives should be implemented to address the lack of knowledge and awareness surrounding sustainable concrete. These efforts should target all stakeholders, including construction companies, clients, architects, and engineers, to promote a better understanding of the environmental benefits, reliability, and long-term value of SC technologies.

Provide incentives for sustainable concrete adoption: Financial incentives, such as tax breaks or grants, should be considered to encourage the adoption of sustainable concrete practices as mentioned in fostering the sociotechnical acceptance function. These incentives can help offset the initial higher costs associated with SC implementation and provide motivation for stakeholders to embrace sustainable alternatives.

Strengthen drivers:

Foster collaboration and knowledge sharing: As a result of Building innovation networks function it can be recommended that collaboration platforms, such as "het Betonakkoord," should be expanded and strengthened. More initiatives, working groups, and living labs should be established to facilitate collaboration between industry, academia, and government. These networks will foster innovation, accelerate the development of sustainable concrete technologies, and facilitate the transfer of knowledge and expertise.

Enhance market accessibility and availability: It can be recommended by considering the result of Building innovation networks and fostering sociotechnical acceptance results, that Collaboration between suppliers and producers should be fostered to improve the accessibility and availability of sustainable concrete materials. Efforts should be made to establish a reliable and scalable supply chain to meet the growing demand in the construction industry. Strategies to mitigate the perceived higher costs of SC materials should also be explored.

7.3 Limitations and Recommendations for further research

7.3.1 Limitation:

One limitation of the current research is the relatively small sample size of the surveyed population within the concrete sector. While efforts were made to include a diverse range of companies, such as the 83 companies involved in the "beton akkoord" initiative, this sample may not fully represent the entirety of the concrete industry. To address this limitation, future research should strive to conduct surveys with a larger number of participants from various sectors within the concrete industry. This would provide a more robust and representative understanding of the challenges and opportunities related to sustainable concrete adoption.

Additionally, the lack of access to the recently released application and its data poses another limitation. The application is considered a valuable tool for assessing the current level of adaptation of sustainable concrete. However, due to the unavailability of released data during the current research, it was not possible to explore the application's effectiveness and analyze its impact on sustainable concrete practices.

7.3.2 Recommendations for Future Research

Comprehensive Research on Different Actors: Given the presence of multiple actors in the concrete sector, it is essential to conduct research to gain comprehensive knowledge about each actor. Future studies should focus on exploring the perspectives, roles, and interests of various stakeholders, such as producers, suppliers, contractors, policymakers, and consumers. By understanding the barriers and barriers faced by each actor, tailored strategies and policies can be developed to drive sustainable concrete practices throughout the industry.

Investigating the Role of Research in Enhancing Adoption: To increase the adoption of sustainable concrete, there is a need for extensive investigation into the role of research in driving change within the industry. Future research should explore the impact of research efforts on promoting sustainable concrete practices. This investigation can involve studying the influence of research findings, dissemination methods, and collaboration between researchers and industry stakeholders. By understanding how research affects adoption rates, strategies and policies can be developed to maximize the impact of research in fostering sustainable concrete practices.

Researching International Regulations: The lack of standardized regulations is a significant challenge in the concrete sector's path toward sustainability. Future research should focus on exploring existing regulations in different countries and assessing their relevance and effectiveness in the concrete industry. Additionally, there is a need to investigate regulations from other industries that have successfully addressed sustainability challenges and assess their applicability to the concrete sector. This research would provide valuable insights into potential regulatory frameworks and best practices that can be adopted to promote sustainable concrete production and usage globally.

References

Akadiri, P. O., Chinyio, E. A., & Olomolaiye, P. O. (2012). Design of a sustainable building: A conceptual framework for implementing sustainability in the building sector. *Buildings*, *2*(2), 126–152. https://doi.org/10.3390/buildings2020126

Alsanad, S. (2015). Awareness, Drivers, Actions, and Barriers of Sustainable Construction in Kuwait. *Procedia Engineering*, *118*, 969–983. https://doi.org/10.1016/j.proeng.2015.08.538

Altarrazi, A. M., Islam, M. S., & Ghaithan, A. M. (2022). Benefits Realization and Application Challenges of Green Concrete Towards Sustainability in Saudi Arabian Construction. *IOP Conference Series: Earth and Environmental Science*, *1026*(1). https://doi.org/10.1088/1755-1315/1026/1/012019

Amaral, R. E. C., Brito, J., Buckman, M., Drake, E., Ilatova, E., Rice, P., Sabbagh, C., Voronkin, S., & Abraham, Y. S. (2020). Waste management and operational energy for sustainable buildings: A review. In *Sustainability (Switzerland)* (Vol. 12, Issue 13). MDPI. https://doi.org/10.3390/su12135337

Arıoğlu Akan, M. Ö., Dhavale, D. G., & Sarkis, J. (2017). Greenhouse gas emissions in the construction industry: An analysis and evaluation of a concrete supply chain. *Journal of Cleaner Production*, *167*, 1195–1207. https://doi.org/10.1016/j.jclepro.2017.07.225

Bergek, A., Jacobsson, S., Carlsson, B., Lindmark, S., & Rickne, A. (2008). Analyzing the functional dynamics of technological innovation systems: A scheme of analysis. *Research Policy*, *37*(3), 407–429. https://doi.org/10.1016/j.respol.2007.12.003

Bergek, A., Jacobsson, S., Carlsson, B., Lindmarki, S., & Rickne, A. (2005). *DYNAMICS OF INDUSTRY AND INNOVATION: ORGANIZATIONS, NETWORKS AND SYSTEMS Track Systems of Innovation, Institutions and Public Policies ANALYZING THE DYNAMICS AND FUNCTIONALITY OF SECTORAL INNOVATION SYSTEMS-A MANUAL*.

Bijleveld, M., & Beeftink, M. (2017). *Dutch construction Climate impact of concrete use in the*. www.ce.nl

Cement and Concrete Sustainability. (2023). Portland Cement Association. https://www.cement.org/sustainability

Conduct a literature review. (2023). University of Arizona.

de Brito, J., & Kurda, R. (2021a). The past and future of sustainable concrete: A critical review and new strategies on cement-based materials. In *Journal of Cleaner Production* (Vol. 281). Elsevier Ltd. https://doi.org/10.1016/j.jclepro.2020.123558

de Brito, J., & Kurda, R. (2021b). The past and future of sustainable concrete: A critical review and new strategies on cement-based materials. In *Journal of Cleaner Production* (Vol. 281). Elsevier Ltd. https://doi.org/10.1016/j.jclepro.2020.123558

Fayyad, T. M., & Abdalqader, A. F. (2020). *Demountable reinforced concrete structures: A review and future directions*.

Geels, F. W. (2002). Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. In *Research Policy* (Vol. 31).

Hesselink, L. X. W., & Chappin, E. J. L. (2019). Adoption of energy efficient technologies by households – Barriers, policies and agent-based modelling studies. *Renewable and Sustainable Energy Reviews*, *99*, 29–41. https://doi.org/10.1016/j.rser.2018.09.031

Javadabadi, M. T., Kristiansen, D. D. L., Redie, M. B., & Baghban, M. H. (2019). Sustainable Concrete: A Review. *International Journal of Structural and Civil Engineering Research*, 126–132. https://doi.org/10.18178/ijscer.8.2.126-132

Kibert, C. J. (2016). *Sustainable construction: green building design and delivery*. John Wiley & Sons.

Knott, E., Rao, A. H., Summers, K., & Teeger, C. (2022). Interviews in the social sciences. *Nature Reviews Methods Primers*, *2*(1). https://doi.org/10.1038/s43586-022-00150-6

Köhler, J., Geels, F. W., Kern, F., Markard, J., Onsongo, E., Wieczorek, A., Alkemade, F., Avelino, F., Bergek, A., Boons, F., Fünfschilling, L., Hess, D., Holtz, G., Hyysalo, S., Jenkins, K., Kivimaa, P., Martiskainen, M., McMeekin, A., Mühlemeier, M. S., … Wells, P. (2019). An agenda for sustainability transitions research: State of the art and future directions. *Environmental Innovation and Societal Transitions*, *31*, 1–32. https://doi.org/10.1016/j.eist.2019.01.004

Küpfer, C., Bastien-Masse, M., & Fivet, C. (2023). Reuse of concrete components in new construction projects: Critical review of 77 circular precedents. In *Journal of Cleaner Production* (Vol. 383). Elsevier Ltd. https://doi.org/10.1016/j.jclepro.2022.135235

Loorbach, D., & Rotmans, J. (2010). The practice of transition management: Examples and lessons from four distinct cases. *Futures*, *42*(3), 237–246. https://doi.org/10.1016/j.futures.2009.11.009

Marey, H., Kozma, G., & Szabó, G. (2022). Effects of Using Green Concrete Materials on the CO2 Emissions of the Residential Building Sector in Egypt. *Sustainability (Switzerland)*, *14*(6). https://doi.org/10.3390/su14063592

Materiaalstromen in de bouw en infra. (2022).

Mavi, R. K., Gengatharen, D., Mavi, N. K., Hughes, R., Campbell, A., & Yates, R. (2021). Sustainability in construction projects: A systematic literature review. In *Sustainability (Switzerland)* (Vol. 13, Issue 4, pp. 1–24). MDPI. https://doi.org/10.3390/su13041932

McConville, J. R., Kvarnström, E., Jönsson, H., Kärrman, E., & Johansson, M. (2017). Source separation: Challenges & opportunities for transition in the swedish wastewater sector. *Resources, Conservation and Recycling*, *120*, 144–156. https://doi.org/10.1016/j.resconrec.2016.12.004

Müller, H. S., Moffatt, J. S., Haist, M., & Vogel, M. (2019). A New Generation of Sustainable Structural Concretes-Design Approach and Material Properties. *IOP Conference Series: Earth and Environmental Science*, *290*(1). https://doi.org/10.1088/1755-1315/290/1/012002

Nederland, B., Marijn, M. M. (, Bijleveld,), Geert, G. C. (, Bergsma,), Krutwagen, B., Maarten, M. A. (, & Afman,). (2014). *Meten is weten in de Nederlandse bouw Uitgevoerd door: CE Delft In opdracht van: Opgesteld door*. www.ce.nl

Ooa, D., & Ioe, D. (2017). *Barriers to Implementation of Sustainable Construction Techniques*.

Peter of Ghent. (2021). *Road Map CO 2*.

Sahin, I. (2006). DETAILED REVIEW OF ROGERS' DIFFUSION OF INNOVATIONS THEORY AND EDUCATIONAL TECHNOLOGY-RELATED STUDIES BASED ON ROGERS' THEORY. In *The Turkish Online Journal of Educational Technology* (Vol. 5).

Schot, J., & Geels, F. W. (2008). Strategic niche management and sustainable innovation journeys: Theory, findings, research agenda, and policy. *Technology Analysis and Strategic Management*, *20*(5), 537–554. https://doi.org/10.1080/09537320802292651

Shen, L. yin, Tam, V. W. Y., Tam, L., & Ji, Y. bo. (2010). Project feasibility study: the key to successful implementation of sustainable and socially responsible construction management practice. *Journal of Cleaner Production*, *18*(3), 254–259. https://doi.org/10.1016/j.jclepro.2009.10.014

Surahyo, A. (2019). Concrete Construction. In *Concrete Construction*. Springer International Publishing. https://doi.org/10.1007/978-3-030-10510-5

Tegan George. (2022). *Semi-Structured Interview | Definition, Guide & Examples*. https://www.scribbr.com/methodology/semi-structured-interview/

UNEP. (2019). Global Status Report for Buildings and Construction. https://www.unep.org/resources/publication/2019-global-status-report-buildings-and-construction-sector

Voß, J. P., Smith, A., & Grin, J. (2009). Designing long-term policy: Rethinking transition management. *Policy Sciences*, *42*(4), 275–302. https://doi.org/10.1007/s11077-009-9103-5

WGBC. (2019). Bringing Embodied Carbon Upfront .

Yeheyis, M., Hewage, K., Alam, M. S., Eskicioglu, C., & Sadiq, R. (2013). An overview of construction and demolition waste management in Canada: A lifecycle analysis approach to sustainability. In *Clean Technologies and Environmental Policy* (Vol. 15, Issue 1, pp. 81–91). Springer Verlag. https://doi.org/10.1007/s10098-012-0481-6

Zhao, Y., Yu, M., Xiang, Y., Kong, F., & Li, L. (2020). A sustainability comparison between green concretes and traditional concrete using an emergy ternary diagram. *Journal of Cleaner Production*, *256*. https://doi.org/10.1016/j.jclepro.2020.120421

APPENDIX I

Articles and Reports that used to identify Drivers and Barriers	
Articles	Alsanad, S. (2015). Awareness, Drivers, Actions, and Barriers of Sustainable Construction in Kuwait. Procedia Engineering, 118, 969–983. https://doi.org/10.1016/j.proeng.2015.08.538
	Altarrazi, A. M., Islam, M. S., & Ghaithan, A. M. (2022). Benefits Realization and Application Challenges of Green Concrete Towards Sustainability in Saudi Arabian Construction. IOP Conference Series: Earth and Environmental Science, 1026(1). https://doi.org/10.1088/1755-1315/1026/1/012019
	Amaral, R. E. C., Brito, J., Buckman, M., Drake, E., Ilatova, E., Rice, P., Sabbagh, C., Voronkin, S., & Abraham, Y. S. (2020). Waste management and operational energy for sustainable buildings: A review. In Sustainability (Switzerland) (Vol. 12, Issue 13). MDPI. https://doi.org/10.3390/su12135337
	Arıoğlu Akan, M. Ö., Dhavale, D. G., & Sarkis, J. (2017). Greenhouse gas emissions in the construction industry: An analysis and evaluation of a concrete supply chain. Journal of Cleaner Production, 167, 1195–1207. https://doi.org/10.1016/j.jclepro.2017.07.225
	de Brito, J., & Kurda, R. (2021a). The past and future of sustainable concrete: A critical review and new strategies on cement-based materials. In Journal of Cleaner Production (Vol. 281). Elsevier Ltd. https://doi.org/10.1016/j.jclepro.2020.123558
	Fayyad, T. M., & Abdalqader, A. F. (2020). Demountable reinforced concrete structures: A review and future directions.
	Javadabadi, M. T., Kristiansen, D. D. L., Redie, M. B., & Baghban, M. H. (2019). Sustainable Concrete: A Review. International Journal of Structural and Civil Engineering Research, 126–132. https://doi.org/10.18178/ijscer.8.2.126-132
	Küpfer, C., Bastien-Masse, M., & Fivet, C. (2023). Reuse of concrete components in new construction projects: Critical review of 77 circular precedents. In Journal of Cleaner Production (Vol. 383). Elsevier Ltd. https://doi.org/10.1016/j.jclepro.2022.135235
	Marey, H., Kozma, G., & Szabó, G. (2022). Effects of Using Green Concrete Materials on the CO2 Emissions of the Residential Building Sector in Egypt. Sustainability (Switzerland), 14(6). https://doi.org/10.3390/su14063592
	Mavi, R. K., Gengatharen, D., Mavi, N. K., Hughes, R., Campbell, A., & Yates, R. (2021). Sustainability in construction projects: A systematic literature review. In Sustainability (Switzerland) (Vol. 13, Issue 4, pp. 1–24). MDPI. https://doi.org/10.3390/su13041932
	Müller, H. S., Moffatt, J. S., Haist, M., & Vogel, M. (2019). A New Generation of Sustainable Structural Concretes-Design Approach and Material Properties. IOP Conference Series: Earth and Environmental Science, 290(1). https://doi.org/10.1088/1755-1315/290/1/012002
	Ooa, D., & Ioe, D. (2017). Barriers to Implementation of Sustainable Construction Techniques.
	Surahyo, A. (2019). Concrete Construction. In Concrete Construction. Springer International Publishing. https://doi.org/10.1007/978-3-030-10510-5

	Yeheyis, M., Hewage, K., Alam, M. S., Eskicioglu, C., & Sadiq, R. (2013). An overview of construction and demolition waste management in Canada: A lifecycle analysis approach to sustainability. In Clean Technologies and Environmental Policy (Vol. 15, Issue 1, pp. 81–91). Springer Verlag. https://doi.org/10.1007/s10098-012-0481-6
	Zhao, Y., Yu, M., Xiang, Y., Kong, F., & Li, L. (2020). A sustainability comparison between green concretes and traditional concrete using an emergy ternary diagram. Journal of Cleaner Production, 256. https://doi.org/10.1016/j.jclepro.2020.120421
Reports	Cement and Concrete Sustainability. (2023). Portland Cement Association. https://www.cement.org/sustainability
	Materiaalstromen in de bouw en infra. (2022).
	Nederland, B., Marijn, M. M. (, Bijleveld,), Geert, G. C. (, Bergsma,), Krutwagen, B., Maarten, M. A. (, & Afman,). (2014). Meten is weten in de Nederlandse bouw Uitgevoerd door: CE Delft In opdracht van: Opgesteld door. www.ce.nl

APPENDIX II

Consent Letter:

□ I, …………………………………, voluntarily agree to participate in this research study interview.

□ I understand that even if I agree to participate now, I can withdraw at any time or refuse to answer any question without any consequences of any kind.

□ I understand that I can withdraw permission to use data from my interview after it, in which case the material will be deleted.

□ I have had the purpose and nature of the study explained to me and I have had the opportunity to ask questions about the study.

□ I understand that all information I provide for this study will be treated confidentially.

□ I understand that in any report on the results of this research, my identity will remain anonymous if preferred to be so. This will be done by not explicitly mentioning my name and disguising any details of my interview which may reveal my identity or the identity of people I speak about.

□ I understand that I am free to contact any of the people involved in the research to seek further clarification and information.

Here follow the names of the people involved in this research who guarantee the agreed use of this consent and the answers provided during the interview".

Researchers: Arash Bemaniyazdi
Project Supervisor: César Casiano Flores
Participant :

Signature of participant :

Date:

APPENDIX III

Questionner:

Introduction

Thank you for participating in this survey on Sustainable Concrete (SC). Your contribution is vital in understanding the current state and potential of SC in the Dutch construction industry. My goal in this research is to expedite the transition towards a sustainable building industry in the Netherlands. I am passionate about understanding the level of adaptation for sustainable concrete and analyzing the drivers and barriers that influence construction companies in their transition. By gaining insights into these factors, I can propose solutions that will effectively support and encourage sustainable practices. Your insights will help identify challenges, funding needs, customer perceptions, and opportunities for collaboration. Together, we can drive sustainable practices and make a positive impact.

First part: General information

1. What is your current job title?
2. How many years of experience do you have in your field?
3. What are your areas of experience?

Second part: Specialized questions

16. According to your perspective, how would you define Sustainable Concrete (SC)?
17. In your opinion, to what extent are research and development related to SC in the Dutch construction industry? (Please provide a range of answers, from very low to very high) Additionally, can you share specific examples of SC technologies that you are familiar with?
18. Do you consider that there is enough funding allocated to SC research and development in the Netherlands?
19. Have you ever been part of a project that used SC? If so, what were the main challenges faced during the project?
20. To what extent environmental concerns are considered when implementing SC in a project?
21. Is the material for SC easily accessible and is there enough availability for entire construction projects?
22. In your opinion, is the initial higher cost of using SC seen as an investment by the customers?
23. Do you think that the availability of SC can continue meeting the growing demand in construction projects?
24. Do you think SC is a reliable material for long-term construction? SC construction, depending on the people we are asking, can be changed.
25. In the circumstances where you have clients, what is the approximate percentage of clients who order Sustainable Concrete (SC) for their structures? Additionally, if possible, what is the volume associated with these orders?
26. Are you aware of any regulations or policies that are hindering the transition to the use of SC/Sustainable Construction?
27. Are you aware of the regulations that support the use of SC?
28. Are you part of collaborations between industry, academia, and government to promote innovation and knowledge sharing in SC technologies, and what specific outcomes were achieved because of these collaborations?
29. What strategies have been used in the Dutch construction industry to engage stakeholders and the public in the development and implementation of SC technologies, and what are the main achievements of such strategies?
30. What are the possible reasons for stakeholders and customers to resist the implementation of SC practices?

Thank you for your valuable input!