Delft University of Technology

MASTER THESIS

Green Concrete: Overcoming Challenges & Limitations for Sustainable Building

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CONSTRUCTION MANAGEMENT & ENGINEERING

Witteveen + Bos

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Sincerely,

Alexandru Zaharia

Delft, June 15, 2023

Executive Summary

This graduation project aims to study the implementation process of green concrete into construction projects in order to promote and achieve a sustainable development of the construction industry. The main research question this thesis strives to answer is *How can green concrete solutions be implemented in construction projects to achieve and promote sustainability, considering the challenges and limitations of adopting innovations in the industry?*, followed by the four sub-research questions; *What is the definition and significance of green concrete in the construction industry, considering its potential to promote sustainability?*, *What are the most common barriers and challenges faced by construction professionals when implementing green concrete solutions in their projects, and how can these be addressed effectively?*, *What are the key factors that influence the decision to adopt green concrete solutions in construction projects, and how can these be leveraged to promote the widespread implementation of these solutions?*, and *What are the current used practices and strategies for integrating green concrete solutions into the design and construction process, ensuring that they are seamlessly integrated into the project and meet the required performance standards?*

In this research, a mixed methodology was used, including a review of the existing literature, an online survey conducted at company level, and semi-structured interviews with various experts in the construction field. These methods resulted in important findings regarding the meaning and importance of green concrete, as well as the challenges it faces and strategies for promoting its use as a reliable construction material.

Green concrete is a construction material that integrates eco-friendly elements throughout its life cycle, including the design, building, and maintenance phases. This material is characterised by its use of recycled materials and avoidance of processes that harm the environment. Green concrete plays a vital role in achieving sustainability goals by minimising environmental impact and promoting resource efficiency in the construction industry. The current definition of green concrete is expanded by this research to include a reduced cement content, incorporation of recycled minerals, lower energy and water consumption, longer lifespan, and the ability to promote environmental, social, and economic sustainability in the construction market.

Based on the results of the online survey conducted within the company, it was found that there was only moderate familiarity with the concept of green concrete among the respondents. This indicates the need for further education and awareness. On the other hand, it resulted that green concrete is seen as important and relevant for the industry, which creates an opportunistic scene for scale-up. The study also revealed that the environment has the greatest influence on the decision-making process when it comes to sustainability, followed by society and economy. The factor analysis highlighted 7 most critical factors that interfere with the decision-making process, including the overall industry support and promotion, the personal traits of individuals such as attitude and beliefs, resources, market status, lack of leadership, collaboration, and communication

barriers and time. Lastly, a relative importance index calculation was performed on the 10 most common barriers to innovation, which resulted in "Short-term thinking" being the most impactful factor for the company's employees, followed by "Fear" and "No clear process".

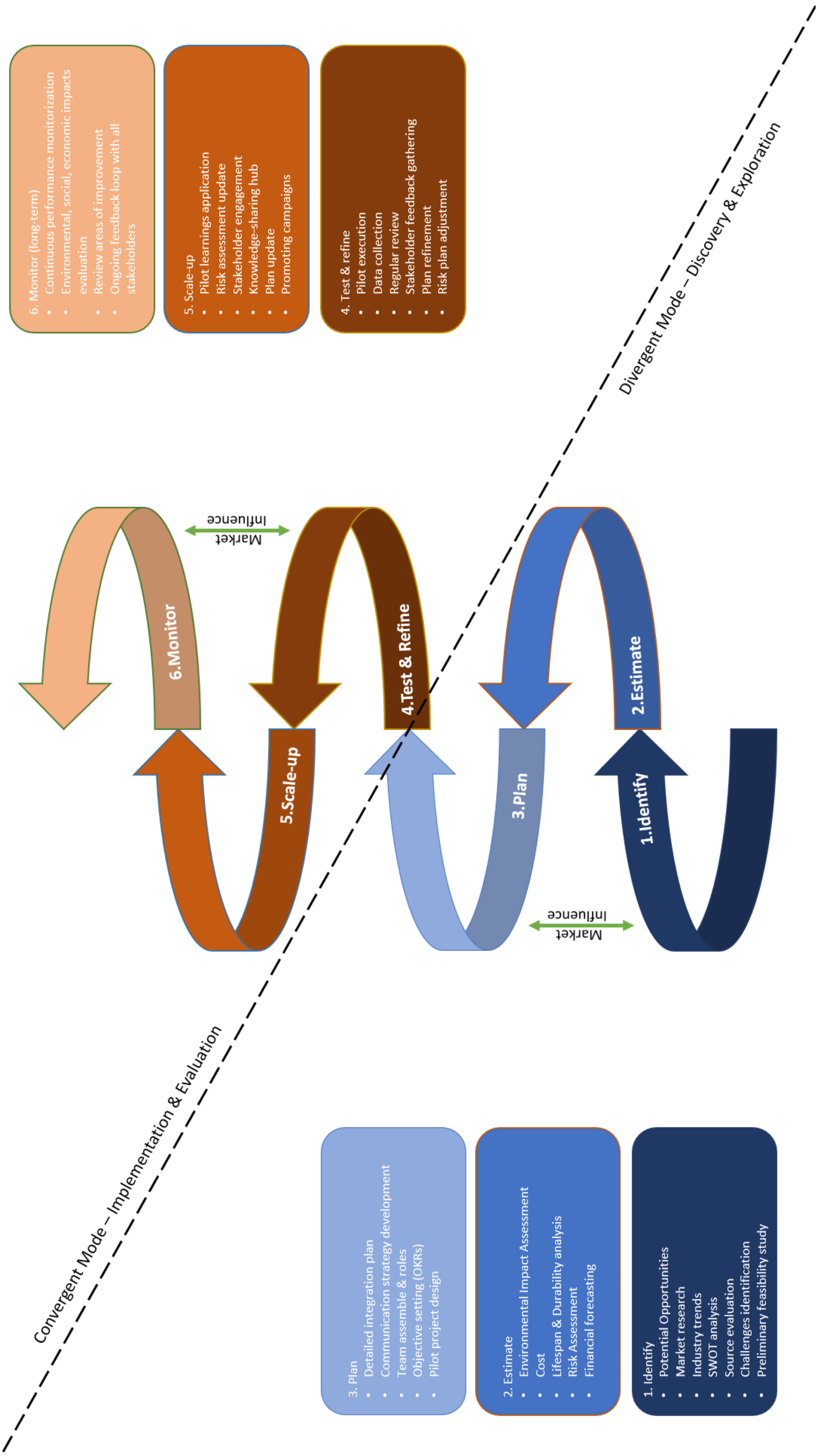
Construction specialists interviewed in this study confirmed the importance of green concrete as a sustainable material and acknowledged its benefits for achieving sustainability goals. Nonetheless, they also stretched the issues in implementing green concrete, such as high costs, performance and durability concerns, and the absence of norms and standards. In addition, various factors were identified that influence the implementation process, including investment, client and contractor decisions, sustainability and environment, innovation and technology, performance and safety, social impact, and openness and collaboration. Collaboration, education, regulatory incentives, and R&D investment are identified as effective strategies to promote successful implementation of green concrete in the construction industry and foster sustainable development.

To integrate all the findings in a systematic approach, a framework was developed to aid the process of implementing green concrete solutions into practical applications. The Green Concrete Integration Model (GCIM), depicted in Figure 6.1, offers a pioneering approach for implementing green concrete in construction projects. Employing a spiral model, the GCIM emphasizes adaptability and continuous improvement. The framework operates in divergent and convergent dimensions - the former involves discovery and exploration, while the latter concentrates on practical implementation.

The GCIM consists of six iterative steps: identification, estimation, planning, testing and refining, scale-up, and monitoring. Each step addresses specific challenges - technical, economic, socio-cultural, and regulatory - and facilitates early problem detection.

Market influences, as identified through a survey, are shaped by personal traits and general perceptions. The GCIM combats the complexity arising from these influences by systematically managing challenges at each stage. Additionally, it highlights the importance of advanced stakeholder management and continuous monitoring of environmental, social, and economic factors.

In summary, the GCIM provides an adaptive and structured framework for efficiently integrating green concrete into construction projects, tackling challenges and optimizing opportunities for sustainable advancements.



Green Concrete Integration Model; Source: Author

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Nomenclature

AA Alternative Aggregates

CAGR Compound Annual Growth Rate

CDW Construction & Demolition Waste

Eco. Economic

EIA Environmental Impact Assessment

Env. Environmental

GCIM Green Concrete Integration Model

IRL In Real Life

LCA Life Cycle Analysis

LCSA Life Cycle Sustainability Assessment

OECD Organisation for Economic Cooperation and Development

OKRs Objectives and Key Results

PMC Product-Market-Combination

RAs Recycled Aggregates

RII Relative Importance Index

SCM Supplementary Cementitious Materials

SD Sustainable Development

SGCIM Specific Green Concrete Integration Model

Soc. Social

TRL Technological Readiness Level

VM Virtual Meeting

Chapter 1

Introduction

As the construction sector has a substantial impact on the environment and natural resources, sustainability has become a fundamental part of modern construction methods. In recent years, green concrete has emerged as a possible answer to construction's environmental issues. Green concrete is a type of concrete that utilises recycled minerals and by-products as its basic ingredients, hence minimising the amount of natural resources utilised and waste produced during construction.

The objective of this master's thesis is to investigate the challenges and limitations for the implementation of green concrete in construction projects and how these can be strategically surpassed in an effort to promote sustainability in the construction sector. A comprehensive literature review, an in-house survey, and a series of semi-structured interviews comprise the study's mixed methodological approach. The mixed methodology approach gives a full investigation of the topic, enabling a broad and nuanced knowledge of the use of green concrete in construction projects.

The remaining sections of this thesis are structured as follows. The 2nd Chapter, gives a review of the current state of research on green concrete in building, based on the literature. This study's methodology is presented in Chapter 3. The results of the internal survey and semi-structured interviews are presented in Chapter 4 and Chapter 5. Finally, Chapter 6 reviews the findings, concludes upon the entire research and makes recommendations.

1.1 Background

In the face of rapid climate change, there is a more than necessary response from society to act and adapt to these changes (Niemeyer et al., 2005). With higher standards of living, the needs of humanity are rising. Therefore, more resources are required, which, unfortunately, are not endless. In this context of change, all human activities are included, and everyone is responsible for making sure that the day of tomorrow comes with assurance and that the quality of life will grow or, at least, stay constant.

Zooming into the construction industry, it represents an important pillar in every country's economy and social status (Ofori, 1990). This status, nonetheless, comes with a price. It is the price of natural resource consumption and pollution resulting from the production of the materials, the construction activities, and the environmental impact during and after the lifespan of a structure.

Despite the COVID-19 worldwide pandemic, the sector picked up the pace at an amazingly fast rate, and it is estimated that in the following 10 years it will grow by 35%

(Elis, 2021). With this growth, the effects of the construction activities will have a greater impact on the environment and its future evolution. As a result, the building sector is a top priority for enhancing sustainable practices to diminish the effects of climate change caused by heavy resource-usage and carbon emissions' pollution (Di Maria et al., 2018).

The main objective of sustainability is for people to live on Earth in peace and harmony for an exceedingly long time. Since it is difficult to come to consensus on specific definitions of sustainability, they change over time and in the literature (Ramsey, 2015). What has remained constant in all the current definitions is the integration of the environment, economy, and society in the meaning of the concept. Related to sustainability is the SD (Sustainable Development) concept, which is defined by Brundtland (1991) as the "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." This thesis will consider the concept of SD for the transition of Green Concrete from innovation towards practical application. Relying on all three pillars of sustainability will aid in comprising a more ample answer to the main research question that this study will strive to answer.

1.2 Problem Statement

"If the cement industry were a country, it would be the third largest CO2 emitter in the world - behind China and the US." (Rodgers, 2018)

As the topic of construction is broad, the focus of this research thesis will fall upon the materials branch, in the class of concrete. This material has its origins very deep embedded in history, and it is one of the most used construction materials. Due to its great properties and versatility, this well-known material is and will be the material-of-choice for future construction projects but also for the maintenance of the old built environment. As an example, only the precast concrete market size is expected to grow at over 5.6% CAGR (compound annual growth rate) from 2021 to 2027 due to fast urbanisation that stimulates the growth of the industry (Pulidindi and Bhalerao, 2021), whereas ready-mix concrete still tops the chart of popularity by 2030 (Digvijay and Onkar, 2022), as seen in Figure 1.1 below.

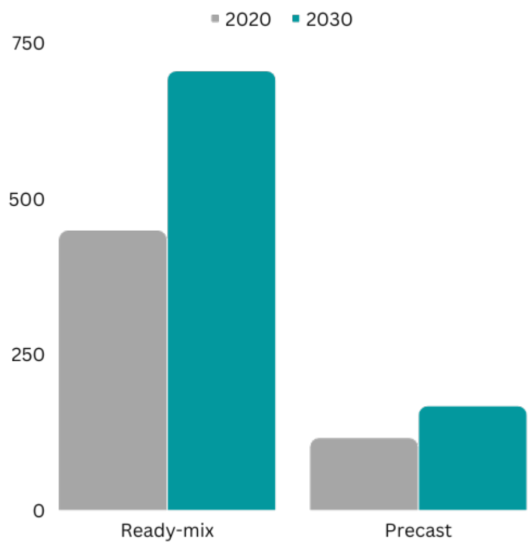

Figure 1.1: Ready-mix concrete & Precast concrete Market by 2030; Source: Author

In 2020 the ready-mix concrete was evaluated at \$448 billion, whereas by 2030 the value is expected to go up to \$704.2 billion (Digvijay and Onkar, 2022). At the same time, looking at the precast concrete, even though with a smaller market valuation, the trend follows the same pattern of growth. In 2020 the value was set up to \$114.78 billion (Insights, 2021) and by 2030 the expectations go up to \$166 billion (Straits Research, 2022).

On the downside, it is estimated that between 4-8% of total CO2 emissions come from the concrete industry, which demonstrates its massive impact on the environment (Lehne and Preston, 2018). More than 4 billion tonnes of cement are blended annually. That is roughly 500 kilograms per person. In other words, humans produce enough cement annually to construct 11,000 Empire State Buildings. At the mentioned rate of growth, the problem of emissions will only get worse if collective efforts are not invested in the problem at hand.

To diminish these undesired effects on the environment, as of late, there are many innovations emerging in the concrete market that promise, if not the same, better properties than the traditional concrete. In practice, this new material can also go under the name of green concrete (Sivakrishna et al., 2020).

The biggest challenge in the construction sector, next to many others, is the implementation phase of innovations with respect to materials. In the current scenario, the well-known Portland cement-based concrete should be replaced with more sustainable versions, as the Portland cement production has the greatest negative impact when creating the concrete mixture.

Looking at the problem through the prism of sustainability, Figure 1.2 retrieved from Bosch Global (2022) and adapted to Hart and Milstein (1999) paper, the environment is not the only concern in the development of an innovation towards becoming a practical application. The other two dimensions, society and economy, need to be included in the decision-making process.

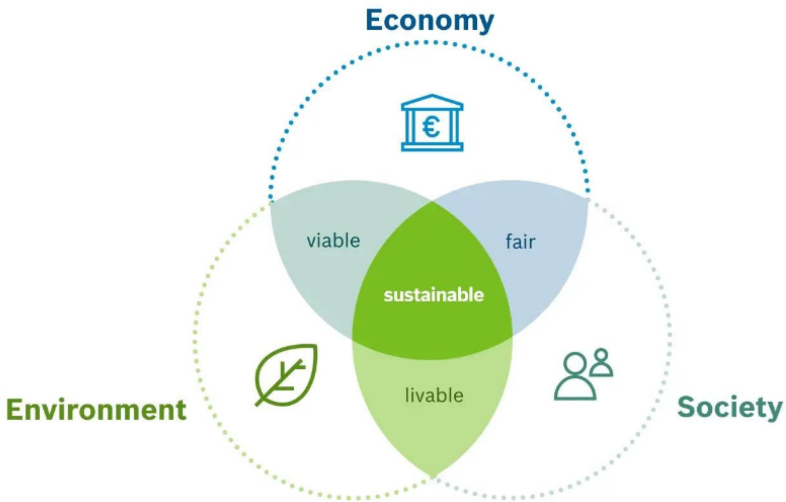

Figure 1.2: Dimensions of Sustainability, retrieved from Bosch Global (2022)

From the start, three main broad categories of challenges can be identified from Figure 1.2. The environmental, social, and economic challenges can interfere with the implementing process of various green concrete solutions. The mentioned three aspects of sustainability do not come as a standalone, but intertwine with one another, a factor which contributes to the complexity of the problem, denoting a sense of subjectivity.

As an example, one issue is that the construction norms and standards have much slower rates of progress than the rate of innovations. This represents an impediment, especially in the design stage of a project. Without a concrete base, pun intended, it is challenging for a designer to go for sustainable alternatives when there is not an extensive design code. It is the same situation for concrete producers, as there are risks in adopting a whole new concrete mix. The problem does not only relate to sustainability from an environmental point of view, but other aspects like economic or social.

In a statement by the Portland Cement Association (Hill, 2013), it was emphasised that there is no universal code for building with green concrete, but lately the interest is rising, and it can be noticed that different institutions, such as governmental bodies, various construction stakeholders, and even academic bodies are putting effort into placing green concrete in the spotlight as a viable solution.

At the current rate of evolution, the industry might not fulfil the Paris Climate Agreement, which argues that the annual emissions of concrete production need to go down at least 16% from now until 2030 (Anderson, 2022). Looking at the numbers of future demand and the desired decrease in pollution, it might seem like a perplexing task. Therefore, isolated try-outs of green concrete implementation need to be scaled-up to a global perspective.

To be noted, reaching the climate objectives stands in a systematic change of sustainable practices. Implementing green concrete in construction projects is just a small component in the sustainable transition. Reducing the carbon emissions and partially solving the waste issue will not be enough if other subsystems are not involved, as for example renewable energy sources or energy-efficient designs.

1.3 Research Objective

The objective of this research is to identify and analyse the challenges and limitations faced by professionals when implementing green concrete and to recommend integrating strategies for these concrete innovations. The perspective used to perform this research is from the consideration of green concrete as being an innovation and following its progress towards a practical application.

In the stage of barriers identification, a series of green concrete solutions will be mapped out with the aim of informing the readers about the current developments of the industry in regard to concrete-like materials and their readiness level for real-world applicability.

1.4 Research Questions

To solve the problem described in the previous chapter, the main research question around which this entire investigation is centred is formulated as:

How can green concrete solutions be implemented in construction projects to achieve and promote sustainability, considering the challenges and limitations of adopting innovations in the industry?

Even though, theoretically, all these green concrete options have great technical specifications and promise great results under any exposure conditions, there are a multitude of challenges that can interfere in the process of the innovation to becoming a practical application. The volatile market, economic issues, disruptions in the supply chain, limited natural resources, lack of interest or knowledge and undeveloped design codes for these new concrete-like materials are just a few of the constraints directly involved with the discussed issue.

Next to the aforementioned hurdles, there are other constraints that enter the equation. It is not only about sustainability from an environmental point of view, but also considering the economic impact and social influences that the new materials imply. Sustainable development presents a growth framework with great interconnectivity between the environmental, economic and social factors and a high degree of subjectivity.

To formulate a pertinent answer to the main research question, additional sub-research questions are needed. Therefore, the following sub-research questions are included:

1. What is the definition and significance of green concrete in the construction industry, considering its potential to promote sustainability?

2. What are the most common challenges and limitations faced by construction professionals when implementing green concrete solutions in their projects, and how can these be addressed effectively?

3. What are the key factors that influence the decision to adopt green concrete solutions in construction projects, and how can these be leveraged to promote the widespread implementation of these solutions?

4. What are the possibilities in terms of practices and strategies for integrating green concrete solutions into the design and construction process, ensuring that they are seamlessly integrated into the project and meet the required performance standards?

1.5 Research Relevance

When it comes to the relevance of this research, there can be two categories identified, theoretical and practical. So far there is a lot of discussion in regard to concrete, new mixtures of concrete, sustainability, and other connected topics, but no implementation framework has been developed to cover the extent of the process.

Relying on the existing research, an overview of the definition and relevance of the green concrete can be made and a series of possible challenges in the implementation can be identified in order to develop a framework that can overcome those hurdles.

1.5.1 Theoretical Relevance

As mentioned before, there is a lot of theory related to the topic that this graduation project is focused on. While it is a great thing that the knowledge is expanding, the downside is that large amounts of information are harder to process, analyse and understand (Rogers et al., 2013). This study will take advantage of the large existing database and filter the necessary information useful for answering the main research question and the sub-research questions.

Defining the concept of green concrete is an initial step in the process of this project. Understanding the concept is key in the process of implementation. The barriers that will be identified are essential in the same way as understanding the concept of green concrete itself.

1.5.2 Practical Relevance

The practical relevance aspect is directly linked to the theoretical aspect, as most of the time they rely on one another.

The outcome of the graduation project will consist in identifying the possible barriers that can emerge in the process of an innovation towards becoming a practical application, listing green concrete solutions feasible for use from a sustainable development point of view and recommend strategies of implementation of those green concrete solutions.

In practice, identifying the possible barriers that can influence the evolution of an innovation is a complex task as it involves many variables which can diminish the chance of taking advantage of an opportunity (Johansen et al., 2015). Centralising the existing vast data and increasing the awareness of the concept of green concrete will help practitioners into being more open to adapting new innovative concrete solutions and understand better the implications that come together with the innovation.

1.6 Research Outline

In Figure 1.3 an overview of phases of this research project is depicted together with an explanation in terms of what each chapter approaches individually. This diagram helps with the planning of the project, making sure that the activities are on track and in the right order.

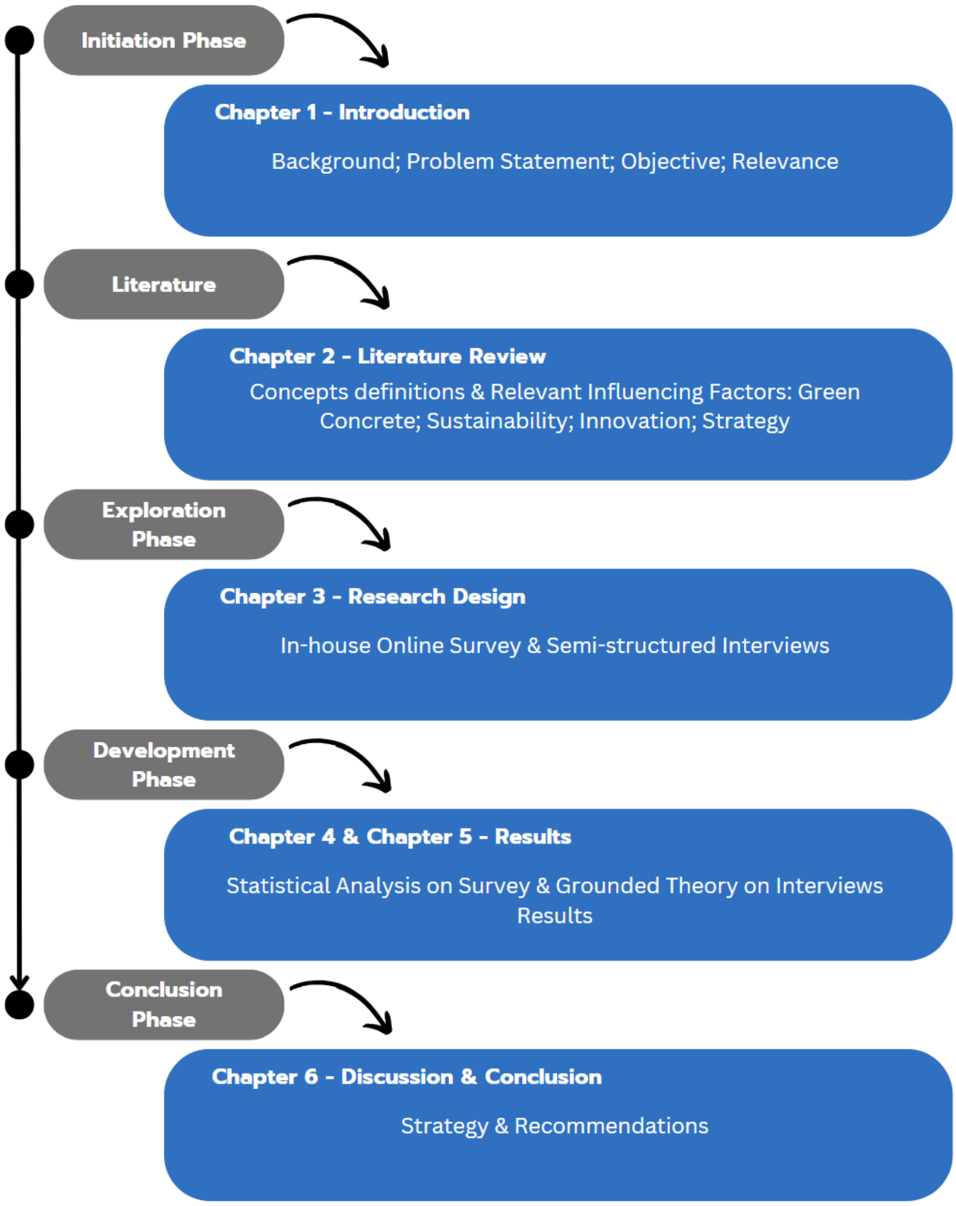

Figure 1.3: Research Outline; Source: Author

Chapter 2

Literature Review

This chapter will constitute the theoretical background on which this research is based. The key concepts involved in this topic will be further explained in detail, covering all aspects incorporated in the main research question and the sub-research questions. The scientific and gray literature studied for this purpose tackles the concepts of green concrete, sustainability in the context of construction, innovations in the construction sector, and the process of implementation of innovations, including challenges and possible strategies.

2.1 Sustainability in Construction

The term 'sustainability' was first coined in 1713 in the context of forestry in Germany, where it entails never harvesting more than the forest produces in new growth (Wiersum, 1995). Since then, the term has grown in many formats and aspects, developing deeper, broader, and more complex meanings.

Today, sustainability is seen as "meeting the needs of the present without compromising the ability of future generations to meet their own needs." - United Nations. This definition was given by Brundtland (1991) and it is still valid for the present time. In essence, sustainability is a societal objective that broadly pertains to the capacity of humans to coexist safely on Earth for an extended period of time.

Typically, three distinct aspects of sustainability are distinguished: environmental, social, and economic, see Figure 1.2. These aspects present a high degree of interconnectedness, and within literature, an understanding of sustainability requires an in-depth overview of the context, which is open to interpretation (Purvis et al., 2018). Some publications stress out the fact that the environmental aspect is the most important (Kotzé et al., 2022), whereas other publications present sustainability as a fluid concept that changes depending on given circumstances.

Sustainability in the construction sector refers to the ecologically responsible and resource-efficient design, construction, and operation of buildings and infrastructure. This includes lowering the negative environmental impact of man-made structures and enhancing the health and well-being of users. This is relevant in the context of construction industry impact, as according to School (2022), the countries which are part of the Organisation for Economic Cooperation and Development (OECD) for construction activities use 25-40% of the total energy and 30% of raw materials, emit 30-40% of total global greenhouse gas and produce 30-40% of solid waste.

Utilising environmentally friendly building materials and techniques is a crucial part of sustainable building. The use of recycled or locally sourced materials, for instance, can lessen the environmental impact of transportation and raw material extraction. Therefore, following the same idea, approaching the concept of green concrete with an open mind can aid in meeting the sustainability goals proposed by the United Nations.

Simultaneously, as previously mentioned, sustainability is a multidimensional system that aims to improve the quality of life for all people by improving the conditions of those with disadvantages, forging valuable bonds between people by emphasising cooperation and social benefits, and implementing economic reforms fuelled by these natural resources (Yılmaz and Bakış, 2015). In simpler words, the interaction of environmental, social, and economic factors draws the overall image of sustainability and, as Yılmaz and Bakış (2015) mentions in their paper, they are inseparable.

2.2 Promoting Sustainability via Green Concrete

2.2.1 Understanding the concept of Green Concrete

Green concrete, which was invented in Denmark in 1998 by Dr. WG, has the goal of replicating classic concrete properties with recycled materials and lower carbon dioxide emissions. Abhijeet Baikerikar described in his article 'A Review of Green Concrete' that green concrete is the concept of embracing and integrating environmental factors into concrete on raw material procurement, mix design, structural design, building and maintenance of concrete structures (Baikerikar, 2014). Suhendro (2014) defines it as 'a concrete that uses waste material as at least one of its components, or its production process does not lead to environmental destruction, or has high performance and sustainability of the life cycle'.

In the current existing literature, a multitude of definitions are attributed to the concept of green concrete. One issue resulting from this variety of definitions is that it is still unknown if the perception and understanding regarding the concept is consistent between the academic environment and the industry (Jin and Chen, 2013). Nonetheless, there is one common denominator in this equation, specifically waste usage, which is vastly spread across all the given definitions of the literature. These waste materials can be used as SCM (supplementary cementitious materials) such as fly ash, silica fume, post-consumer glass, and recycled concrete or as AA (alternative aggregates) (Liew et al., 2017).

As one of the biggest consumers of natural resources in the world, concrete production has been looked at by experts as a possible place for construction and demolition waste (CDW) and a source for recycled aggregates (RAs) to be used in new concrete life cycles. Although the amount that can be added depends on the material, these additions frequently give concrete stronger or additional features, such as durability and thermal insulation, while employing recycled materials that would otherwise wind up in a landfill.

Some of the most popular waste categories and prime materials for obtaining eco-concrete are given in Table 2.1.

Agricultural Waste	Industrial Waste	Municipal Waste
Rice husk ash	Fly ash	Glass
Corn cob ash	Silica fume	Plastics
Sawdust ash	Granulated blast furnace slag	Paper

Table 2.1: Types of waste used as SCM to produce green concrete (Liew et al., 2017)

Since cement is the largest contributor of carbon dioxide emissions in concrete, many have concentrated on alternatives to reduce the amount of cement required per batch, particularly industrial waste products from foundries, quarries, power plants, feed mills, and other sources. However, there are alternative aggregates, such as recycled concrete, glass, and plastic. In addition to substituting cement, aggregate, or sand, businesses can save water by adding super-plasticisers or other water-reducing admixtures to concrete, thereby conserving water during the pouring process.

The list of green concrete solutions can be extensive based on the current supplementary cementitious materials, and it must be underlined that in some cases, the complete replacement of Portland cement might not be possible.

Nowadays, based on the interest in sustainable concrete options, the most popular choices in terms of cement replacement are fly ash, blast furnace slag, silica fume, rice husk ash (RHA) and post-consumer or waste glass. Whereas, in terms of aggregates, the list includes post-consumer glass, recycled concrete aggregate (RCA), waste plastic and foundry sand.

Combining different ratios of different SCM with diverse AA can result in a large palette of green concrete mixtures. The ideal scenario would be to replace the Portland cement-based concrete entirely. A good example is the geopolymer concrete, where fly ash and ground granulated blast furnace slag are used as complete replacement for cement in concrete (Hassan et al., 2019). Another promising innovation that has recently seen the light of the market is biochar-augmented carbon-negative concrete. It typically combines less CO2-intensive production methods with a final product that cures with carbon dioxide recovered from industrial facilities (Chen et al., 2022). Other variations of green concrete are bio-based concrete (using biological materials or processes), ashcrete (with fly ash resulted from coal burning), ferrock (steel waste and silica from glass as binders; it absorbs CO2 during its curing process), hempcrete (hemp fibres and lime as binders), etc.

Given the great number of green concrete options that are currently in the market or still under development, a series of criteria must be fulfilled by a concrete solution to be labelled as green. These criteria were created with a sustainable development in focus and the most common are as follows (Swamy, 2001; Zhao et al., 2020; Suhendro, 2014; Garg and Jain, 2014):

- Reduced cement content: Typically, supplementary cementitious materials (SCMs) such fly ash, slag, and silica fume are used to partially substitute cement in green concrete. This minimises the cement production's embodied energy and carbon emissions, making the concrete more environmentally friendly.
- Incorporation of recycled resources, like aggregates and even recycled water.
- Durability as longer service life reduces the need for maintenance or replacement, therefore lowering the negative impacts over the life cycle of the structure.

- Low energy consumption, such as self-compacting concrete and high-performance concrete, often utilise less energy than conventional methods.
- Low carbon footprint, not only in the life stage, but also for the production process.
- Low water consumption.

There is no definite prioritisation of the listed factors based on what could make concrete greener, as it is highly depended on the goals of the project and the stakeholders desire. However, based on an article from Ahmed et al. (2019) and two websites (Hundertmark et al., 2022), (The Concrete Centre, n.d.) a possible rank is illustrated in Figure 2.1. To be noted, the values assigned to the criteria in the Figure 2.1 are not reflecting any quantitative measurements, but reflect a subjective judgement in order to represent graphically the list.

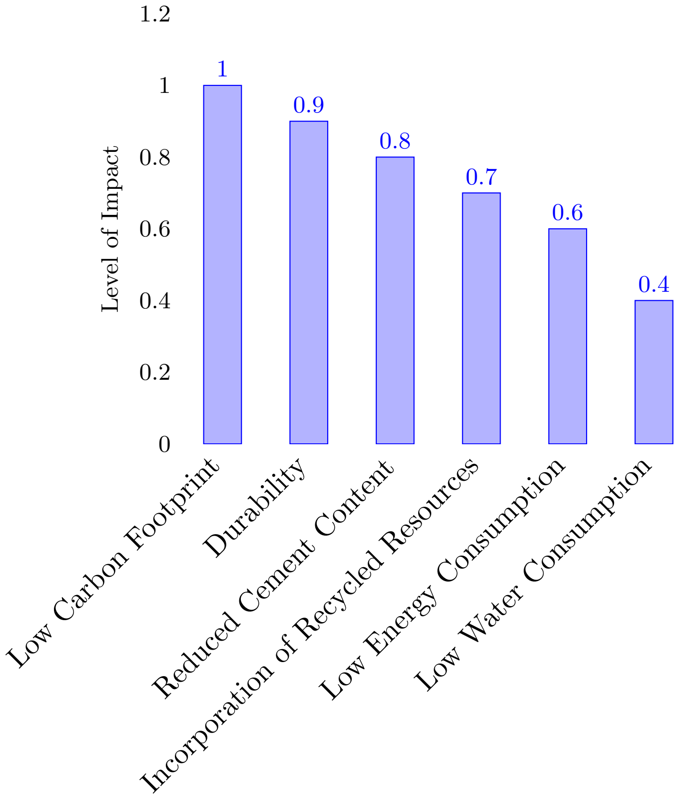

Figure 2.1: Prioritisation of criteria for green concrete; Source: Author

The carbon footprint of concrete is a critical factor in green concrete. Cement production alone is responsible for 8% of total carbon dioxide emissions, as noted by Hundertmark (2022), so any concrete solution with a low carbon footprint is beneficial. Meanwhile, durability is another critical factor to consider when making environmentally friendly concrete. Durability affects how long buildings made of concrete will last and how much they will cost to maintain. By making concrete more durable, it can resist damage from the environment and make buildings, bridges, highways, and other structures last longer. This means that there will be less need to repair or replace structures, which saves resources like energy and money.

The amount of cement used in concrete is another important factor in green concrete, as it affects both the carbon footprint and durability of the material. Cement is the most energy-intensive and polluting component used in concrete. By using less cement or replacing it with other materials like fly ash, slag, or silica fume, concrete can be both more environmentally friendly and technically sound. Additionally, the use of recycled resources in concrete can reduce the demand for natural resources and minimise waste. By using recycled aggregates or water, waste can be minimised, and resources can be used more efficiently.

Finally, green concrete should also consider the energy and water usage during its production and transportation. Low energy usage is critical in reducing fossil fuel consumption and emissions. Self-compacting or high-performance concrete, for example, can streamline building procedures and conserve energy. Meanwhile, low water use can help save water resources and minimise pollution. These criteria are essential in promoting sustainable construction and creating environmentally friendly concrete.

2.2.2 How 'green' is the 'green' concrete?

As explained in the previous Subchapter, a concrete mixture could be labelled as green if multiple criteria are fulfilled. Therefore, this Subchapter will analyse the impact of green concrete on environment, society, and economy, and it will investigate if there is any real added value to the construction industry.

In most of the cases, the term 'green' makes direct reference to sustainability in terms of environment. As mentioned in Chapter 2.1, the environment, in some publications, is seen as the most important factor in the sustainability equation (Kotzé et al., 2022). That is why an Environmental Impact Assessment (EIA) is an important factor in assessing the impact and influence of green concrete. EIA is the evaluation of the environmental consequences of a proposed plan, policy, program, or initiative before a decision is made to move forward with the action (MacKinnon et al., 2018).

Since green concrete can be labelled as an industrial product, a Life Cycle Analysis is used to determine the impact on the environment, but since the other two dimensions of sustainability are also important, a Life Cycle Sustainability Assessment is preferred.

When it comes to green concrete, an initial analysis can examine the extraction of basic materials, auxiliary materials, and equipment; production, use, and disposal; and auxiliary equipment (Daniel et al., 2004). However, in some situations, the impacts on the environment, society, and economy cannot be quantified, for example the long-term effect on climate change, landscape quality or life quality in or nearby the area of development, people's perception or satisfaction. With this, the interconnectivity of the three sustainability factors is proven. The environment can not be treated as a singular dimension without involving the social aspects, which further develop in economic factors. In this case, without quantifiable factors, approximate reasoning methods, which include utilisation of information from analogous EIAs, expert opinion, and community sentiment can be engaged in the decision-making process. This is also known as fuzzy logic, which is a type of multiple-valued logic in which the truth value of variables can be any real number between 0 and 1. It is used to manage the notion of partial truth, in which the truth value can range from completely true to completely false.

Given the large number of variations in terms of green concrete, performing a full life cycle sustainability assessment is strongly influenced by the mix design of the chosen concrete. Different materials involved in the concrete mixture means different processes and outcomes for the final assessment.

Generally, to perform a LCSA on a single variation of green concrete, a detailed analysis of the environmental, social and economic factors are involved starting from the extraction stage of raw materials or waste procurement until the disposal stage.

According to Muralikrishna and Manickam (2017); Daniel et al. (2004), in a simplistic manner, there are 5 stages a full LCSA follows. The first stage is extraction of raw materials such as aggregates, cement in some cases, and water, which are utilised in the manufacturing of green concrete. The second stage is production of green concrete, which includes the manufacture of cement or supplementary cementitious materials, the mixing of aggregates and water, and the addition of any additives required to improve the material's qualities. The third stage is transportation of raw materials and completed goods to and from the production site. The specific effects of transportation will depend on where each part of the supply chain is, what kind of transportation is used, and how far it has to go. Fourth stage is use of green concrete in building projects. Lastly, the fifth stage is disposal of green concrete at the end of its lifetime. A simple representation of the LCA stages is illustrated in the flow chart diagram 2.2 adapted from Marinković (2013), followed by a list of possible impacts on the environment, society, and economy for each of the LCSA stages.

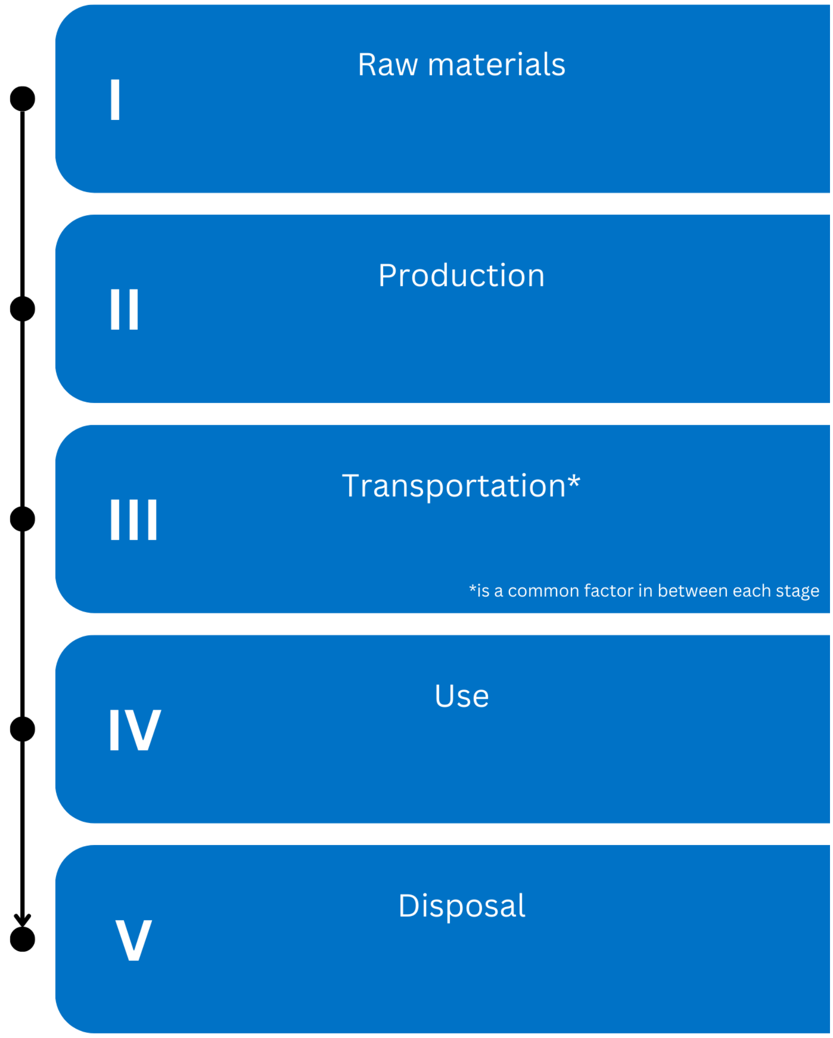

Figure 2.2: Simple flow chart diagram for the LCSA stages of concrete; Adapted from Marinković (2013)

1. Extraction of raw materials such as aggregates, cement, and water, which are utilised in the manufacturing of green concrete, see Table 2.2.

Impacts	Effects
Env.	Biodiversity disruption (Watts, 2021).
	Land degradation; soil, water and air pollution (OECD, 2014).
	Greenhouse gas emissions; great energy consumption (Amato, 2013).
Soc.	Displacement of local communities.
	Harsh working conditions (Britannica, 1999).
	Possible loss of biodiversity and cultural heritage.
	Increased risk of human rights violations, corruption and conflict (Mancini and Sala, 2018).
Eco.	Job creation and economic development for the area of the extraction activity.
	Reduced costs of energy and emissions by using alternative cementitious materials (Hundertmark et al., 2022; Al-Hamrani et al., 2021).
	Increased demand for waste materials such as fly ash, slag and recycled concrete (Al-Hamrani et al., 2021; Meglin et al., 2021).

Table 2.2: Extraction of raw materials for green concrete - Impacts on Sustainability

2. Production of green concrete, which includes the manufacture of cement, the mixing of aggregates and water, and the addition of any additives required to improve the material's qualities, see Table 2.3.

Impacts	Effects
Env.	Air pollution and greenhouse gas emissions from all processes used during production.
	Water pollution from the use of chemicals and waste disposal.
	Noise pollution and land use impacts from production facilities.
Soc.	Health and safety risks for workers involved in the production process.
	Noise pollution and other disruptions to nearby communities.
	Access to employment opportunities in the industry (Hundertmark et al., 2022).
Eco.	Cost of energy and raw materials required for production.
	Job creation and economic growth in the industry.
	Potential for cost savings through the use of more sustainable production methods or materials.

Table 2.3: Production of green concrete - Impacts on Sustainability

3. Transportation of raw materials and completed goods to and from the production site. The specific effects of transportation will depend on where each part of the supply chain is, what kind of transportation is used, and how far it has to go, see Table 2.4.

Impacts	Effects
Env.	Emissions of greenhouse gases and air pollutants from the use of fossil fuels in transportation.
	Unintentional spills or leaks during transit that cause water contamination (OECD, 2014).
	Due to the development of transportation infrastructure, there will be changes in land use and habitat degradation (Asher et al., 2020).
Soc.	More pollution from traffic and noise in communities near transportation routes (Suhendro, 2014).
	Risks to the health and safety of transportation workers, such as accidents or exposure to pollutants (Al-Hamrani et al., 2021).
	Disruption of local communities and cultures during the building of transportation infrastructure (Vishwakarma and Uthaman, 2020).
Eco.	Higher shipping costs because of longer distances or different handling needs (Liew et al., 2017).
	Getting raw materials or selling goods in foreign markets or from foreign suppliers.
	Congestion can slow down or stop transportation networks (Al-Hamrani et al., 2021).

Table 2.4: Transportation of green concrete - Impacts on Sustainability

4. Use of green concrete in building projects. Specific impacts can vary depending on the specific context and conditions of the construction project, see Table 2.5.

Impacts	Effects
Env.	Reduced greenhouse gas emissions as a result of using SCMs such fly ash, slag, or silica fume, as well as less cement (Suhendro, 2014).
	Reduction in the use of energy and water as natural resources (Vishwakarma and Uthaman, 2020).
	Decreased air pollution and better air quality as a result of lower carbon emissions from the manufacture of concrete.
Soc.	Safer and healthier working and living environment in the building by using non-toxic and low emission materials (Al-Hamrani et al., 2021).
	Better quality and longer life-spans of the structure when using high-performance concrete, resulting in lower maintenance costs (Suhendro, 2014; Zhao et al., 2020).
	Better sound insulation and thermal performance, creating a more comfortable living environment (Zhao et al., 2020).
Eco.	Lower construction costs as a result of using locally accessible resources and effective construction techniques (Liew et al., 2017)).
	Reduced handling and transportation expenses as a result of the use of stronger and lighter materials (Liew et al., 2017; Hundertmark et al., 2022).
	Lowered energy expenditures during the building's lifespan as a result of increased energy efficiency (Suhendro, 2014).

Table 2.5: Use of green concrete - Impacts on Sustainability

5. Disposal of green concrete at the end of its useful life, see Table 2.6.

Impacts	Effects
Env.	Landfilling green concrete can lead to the release of harmful pollutants and greenhouse gases into the environment, contributing to soil erosion, air and water pollution, and climate change.
	Recycling green concrete can reduce landfill waste and preserve natural resources, but it can also consume significant amounts of energy and water, generate waste, and emit pollutants (Vishwakarma and Uthaman, 2020).
	Reusing green concrete in construction projects can reduce the need for natural resources and divert waste from landfills, but it may require additional transportation and processing and may not always be feasible.
Soc.	Health and safety: Placing green concrete in landfills can be dangerous for the health and safety of workers and neighbourhood, especially if the waste contains dangerous materials (Sandanayake et al., 2020).
	Recycling and reusing green concrete can help create jobs in waste management, construction, and other related fields (Suhendro, 2014).
Eco.	Recycling green concrete can be costly due to transportation, processing, and quality control expenses. However, it can offset material and disposal costs and generate revenue from recycled materials. Land filling green concrete may also be expensive, particularly if it contains hazardous materials that require special handling and disposal. (Alqahtani et al., 2021; Fattah et al., 2017).

Table 2.6: Disposal of green concrete - Impacts on Sustainability

Considering the aforementioned stages a full LCSA entails, each stage influences the environment, society, and economy differently depending on the type of green concrete and the given context where and how that specific concrete mixture is used.

Green concrete is considered to be a more sustainable and overall better solution compared to traditional concrete. While it may not solve all the problems in the concrete industry, it does have the potential to reduce waste, be more energy-efficient, and reduce carbon footprint. It also has the ability to create jobs at all stages of the life cycle assessment. However, the use of green concrete is still low in practice due to the conservative attitude of the industry. The challenges include the use of potentially dangerous additives, supply chain disruptions, and technology-related issues. In addition, green concrete needs to be integrated with other sustainable practices, such as energy-efficient building design and renewable sources of energy. One-size does not fit all, and the potential of green concrete to promote sustainability needs to be evaluated on specific scenarios. This is why innovation is required to successfully implement green concrete in the industry. Through research and development, new technologies and strategies can be created to address the challenges and limitations of using green concrete, ultimately leading to a more sustainable and eco-friendly construction industry.

2.3 Innovation towards Practical Application

Innovation can be defined as an introduction of novel concepts, procedures, or technologies. It is the process of creating something new or enhancing old concepts, goods, or procedures. Innovation is essential for a number of reasons, including fostering economic growth, enhancing the quality of life, and resolving societal issues. Identifying the problem that an innovation is intended to answer and testing it in real-world settings are the keys to making it applicable. This aids in identifying potential challenges and refining the innovation for optimal use. A good innovation should also be user-friendly, dependable, and inexpensive. With these characteristics, innovations can be transformed into useful applications that improve the lives of people.

2.3.1 Innovations in Construction

Construction is an essential industry that contributes to the creation of the built environment. As people's wants and requirements evolve, the building industry must adapt to meet these new difficulties. Therefore, innovation is necessary for the sustained prosperity of the building business. By creating innovative processes and materials, construction firms may remain ahead of the curve and provide clients with projects that match their ever-changing demands. Those who fail to innovate in a market that is intensely competitive will swiftly fall behind. For this reason, construction businesses must always seek methods to enhance their operations. Those who can accept change and innovate will prosper in this constantly evolving industry (Paredes, 2022).

According to a survey by McKinsey and Company (Agarwal et al., 2022), the construction sector adopts innovations more slowly than other industries. In actuality, less than one percent of construction businesses' income is invested in technological research and development. This investment is much lower compared to the 3.5% and 4.5% invested on innovation by the automobile and aerospace industries, respectively. There could be many reasons why such little attention is given to innovation in the construction context, but according to Reichstein et al. (2005) "the liabilities of immobility and unanticipated demand" is what separates the innovative appetite of the construction sector from other industries.

There are several ways to classify types of innovation, but common categories include (Miłkowski, 2022; Henderson and Clark, 1990; Shavinina, 2003) Product Innovation, which refers to the introduction of new or improved products or services; Process Innovation, which refers to the introduction of new or improved methods of production or delivery; Business Model Innovation, which refers to the introduction of new or improved ways of creating, delivering, and capturing value; Organisational Innovation, which refers to the introduction of new or improved organisational structures, processes, or management practises; Strategic Innovation, which refers to the introduction of new or improved ways of creating and sustaining competitive advantage; Societal Innovation, which refers to innovations that address social and environmental challenges and contribute to the well-being of society; Disruptive Innovation are innovations that disrupt existing market or industry structures, creating new markets and value networks; Incremental Innovation, which refers to small, step-by-step improvements to existing products, processes, or business models; and finally, Radical Innovation, which refers to a major breakthrough that creates a new category or fundamentally changes the way things are done.

Analysing the given above types of innovations, green concrete could be found more or less in any of the above categories. The industry of concrete is a significant pillar in the current times and any innovative idea can add value to the build environment.

Even though the slow movement towards better practices is well known in the construction sector, innovation happened, making concrete greener. Some of the most popular innovations and trends of green concrete reflect upon alternative binders, recycled aggregates (Sivakrishna et al., 2020), self-healing concrete (Amato, 2013), prefabrication and modular construction, carbon-capture technologies and digitalisation.

Alternative Binders: Portland cement is one of the major carbon pollutants in the production of concrete. In an ideal case, a full replacement of the Portland cement is desired to make the concrete more environmentally friendly. For this purpose, alternative binders are developed, like for example geopolymer cement (Weil et al., 2009) which is made out of industrial waste or calcium sulfoaluminate cement (Juenger et al., 2011), from a mix of limestone, gypsum, and clay. Looking further at the geopolymer concrete on how it can add value to the sustainability goals and ambitions, it has reduced carbon emissions for production as the manufacturing temperature is way lower than in the case of Portland cement (Crawford, 2022). In addition, the geopolymer relies on waste for the final mixture, therefore it diverts waste from landfills while reducing the need for virgin resources (Hayes, 2023).

Recycled Aggregates: Crushed concrete is one of the most popular forms of recycled aggregate. It can be used as a natural aggregate substituent in the concrete production process, in this way reducing the need for natural aggregates, eliminating the negative effects of mining and extraction and also minimising the amount of waste that ends up in the landfill (Bamigboye et al., 2022).

Self-healing Concrete: The self-healing concrete is a type of concrete that has in its integrity micro-capsules that release healing agents when fractures appear. Over time, self-healing concrete can lower maintenance and repair costs because it can patch up minor cracks before they get bigger and become more expensive to fix. As a result, there is less waste because there is less need for resource-intensive repairs and replacements (Dong et al., 2013; Jonkers, 2007).

Prefabrication: It is a method of producing constructive elements in a controlled environment, followed by transportation and assembly on-site. The advantages of this method are represented by the decrease of waste, better quality, greater productivity and also a reduced construction time. On top of that, the CO2 emissions can be reduced by using energy-efficient manufacturing processes (Chauhan et al., 2019).

Modular Construction: This method involves the previously mentioned method, prefabrication. Units or modules are puzzled together on the spot at the construction site, resulting in a full structure. In this manner, as in the case of prefabrication, a reduction of time, waste, and energy efficiency can be reached (Subramanya et al., 2020).

Carbon-capture Technology: As the name speaks for itself, this technology can capture the CO2 emissions resulting from different industrial processes and store them underground or even make use of them in other applications. In regard to the cement industry, which is highly CO2 emitting, this could prove valuable by capturing those emissions and lowering the impact of the concrete industry on the environment (Pal et al., 2023).

Digitalisation: Building Information Modelling or, also called, BIM is a digital technology that has caught the eye of the industry in recent years. By creating digital models or twins of buildings or any structure, it allows any stakeholder involved in the construction project to optimise the construction process and even identify issues in an early stage of a project. This technology is essential in reducing waste and increasing overall the performance of the building (Al-Ashmori et al., 2020). A good example of a successful integration of technology in practice is the 3D printing method. By creating elements with high precision and great efficiency in terms of materials, the waste produced after the construction process is considerably diminished (ArchDaily, 2022). Next to that, as of latest, 3D printing can also be performed on-site resulting in less emissions from transportation and greater efficiency in terms of building processes.

An overview of possible benefits and emerging drawbacks for the aforementioned innovations in constructions are illustrated in Figure 2.3. The image is based on information coming from multiple sources as follows: alternative binders - Juenger et al. (2011); Serdar et al. (2019); recycled aggregates - Wang et al. (2021); Kenai (2018); self-healing concrete - Mahajan (2023); Patil (2021); prefabricated and modular construction - Constructor (2023); BuilderSpace (2022); carbon-capture technology - Rhode (2021); Davis (2019); digitalisation - Rangaiah (2021). It is important to assess the drawbacks of an innovation before proceeding with it, and not only focus on the benefits, as the risks can be considerably high. Knowing the downsides and balancing them with the benefits would result in the end in a more sustainable decision that would have the least effect on the environment and satisfy the society's needs in an economically responsible approach.

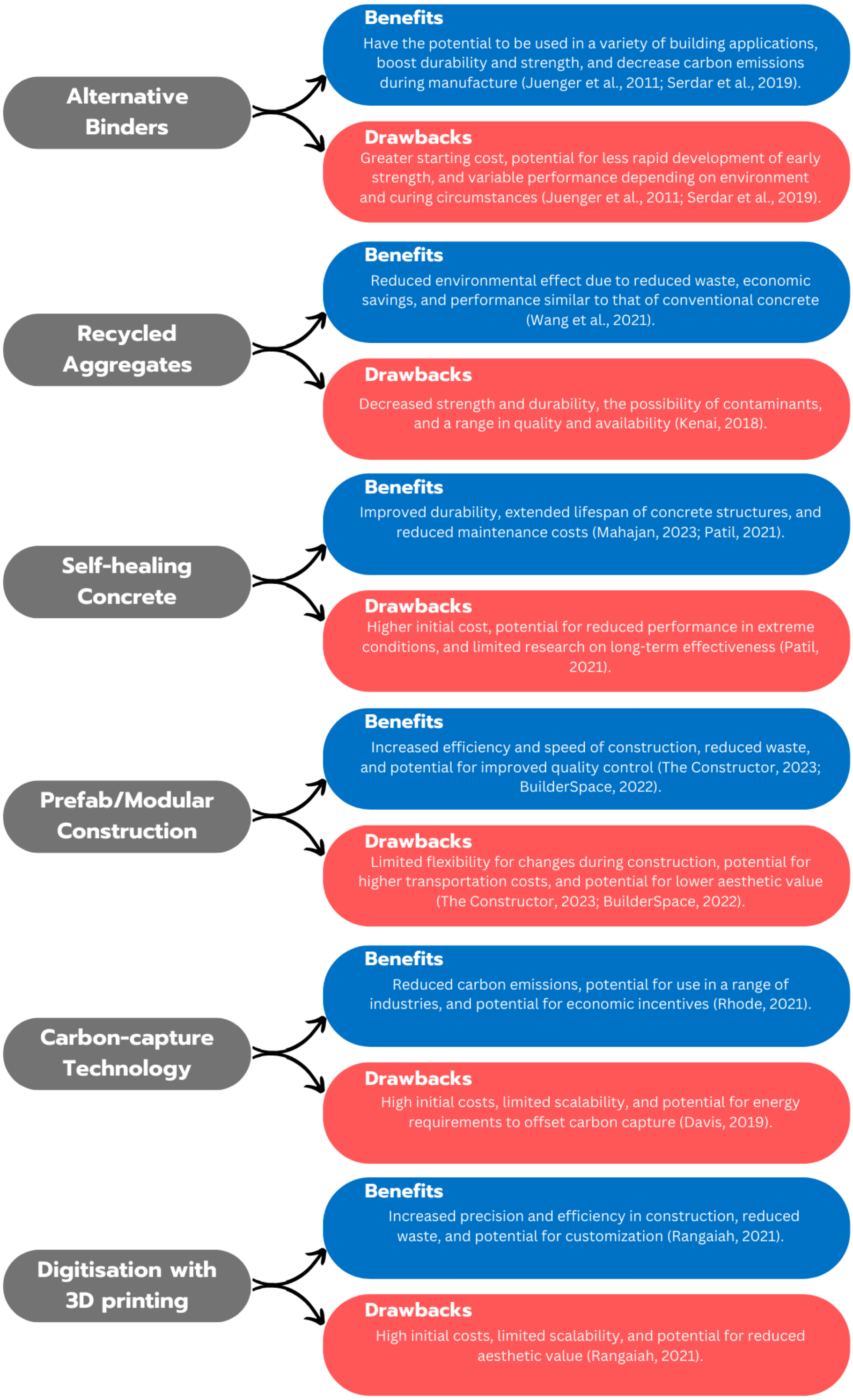

Figure 2.3: Benefits and Drawbacks on Innovations in Constructions; Source: Author

2.3.2 Challenges and Limitations to Innovation

Challenges and limitations for innovations refer to obstacles and difficulties that impede the effective application of new technology, products, or processes in an industry. In the articles of Gower (2022); Kirsner (2018); Tanner (2020) ten most common barriers to innovation can be identified including fear, lack of leadership, short term thinking, lack of capacity or resources, lack of collaboration, lack of focus, limited time, confusing process, lack of urgency and too many non materialised ideas. These obstacles might be classified as technological hurdles, economic barriers, social barriers, and institutional barriers, among others.

Technical obstacles are inherent limitations of technology, such as its dependability, longevity, or performance. Economic obstacles are expenses associated with the implementation of an invention, such as the costs of research and development, production, and adoption. Social obstacles are the attitudes and opinions of individuals and organisations about innovation, such as a lack of knowledge or comprehension of the technology. Institutional obstacles are the rules, policies, and processes that govern the application of the invention, such as the absence of standards or certificates (Liew et al., 2017).

In the construction business, for instance, the deployment of green concrete as an innovation may encounter technical obstacles, such as the need for more research to increase its compressive strength and durability. The broad deployment of green concrete may also be hindered by economic hurdles such as increased production and adoption costs. A lack of awareness and comprehension of the advantages of green concrete among construction professionals may constitute a social barrier. In addition, institutional obstacles, such as the absence of standards and rules for the use of green concrete in construction projects, may impede its adoption. Table 2.7 contains a list of current challenges and limitations to the implementation of green concrete, with a differentiation in terms of their nature.

Consequently, it is crucial to identify and understand the barriers and constraints of innovations in order to overcome them and support the effective deployment of new technologies, products, or processes.

Nature of Challenges	Challenges
Technical challenges (Griffin et al., 2010; Agarwal and Garg, 2018)	Lack of testing and standards
	Lack of knowledge and skills
	Lack of technical specifications
	Uncertainty about durability, performance and compatibility
	Quality control and quality assurance
Economic challenges (Griffin et al., 2010; Lee, 2021)	Limited availability and scalability
	Higher initial costs
	Lack of incentives, subsidies or tax credits
	Low market demand
	Quantification of environmental benefits and life cycle cost
Social and cultural challenges (Griffin et al., 2010; Suhendro, 2014)	Stakeholder engagement
	Awareness
	Knowledge
	Acceptance
	Fragmented supply chain
	Conservative attitude towards change
	Lack of education and training
	Wrong perception
Regulatory challenges (HOUSE, 2018; Union, 2016)	Building codes and regulations
	Building permits

Table 2.7: Challenges to Innovation

Each of the enlisted challenges influence the implementation of green concrete in current practices. The development and application of green concrete could be slowed down by technical obstacles such as lack of knowledge and experience. For instance, certain businesses can lack the skills and experience required to create and test substitute binders, which can impede the broad use of green concrete.

Economic obstacles, like high upfront prices and a lack of financing choices, can significantly affect the implementation process. Even though green concrete has long-term economic advantages, businesses could be hesitant to invest in it because of the higher initial expenditures.

The adoption of green concrete can also be hampered by social and cultural impediments, such as a lack of knowledge and education and an aversion to change. Because green concrete differs from conventional construction methods or because they are unfamiliar with it, certain stakeholders may be reluctant to make the switch.

Patents and licence agreements are two examples of legal restrictions that may impede the creation and spread of green concrete. Companies' capacity to create and invent sustainable alternatives may be hampered if they lack access to the requisite patents or licensing agreements.

Furthermore, the public's ignorance of the advantages of green concrete may also have an effect. Without a clear awareness of the advantages of green concrete, there might not be a significant public demand for environmentally friendly substitutes, which could delay the development and application of green concrete in the building sector.

2.3.3 Overcoming the Challenges & Limitations of Implementing Green Concrete

Finding a suitable solution for each challenge that green concrete is facing is a complex task as it involves many variables and implications. Overcoming these limitations require an in-depth understanding of the issues by combining quantitative measurements and qualitative interpretations. Each variation of green concrete may or may not have the same challenges, therefore the problems need to be approached contextually with precise-given project information.

To overcome the challenges listed in the previous Subchapter, see Table 2.7, numerous solutions are identified in the literature.

- Collaborate (working with others for common goals) and create a knowledge-sharing attitude: Promoting the usage of green concrete can be accomplished through stakeholder cooperation (working with others to achieve own goals) and knowledge exchange within the construction sector. Collaboration among academics, architects, engineers, contractors, and suppliers is one example of this, as well as knowledge exchange through seminars, workshops, and training courses (Castañeda and Cuéllar, 2020).

- Incentivise and create or update regulations: Governments have the power to enact laws and incentives to promote the usage of green concrete. These can include tax breaks, financial assistance, and laws that demand the use of green concrete in public construction projects (Mazzarol, 2020).

- Educate in order to raise awareness: Campaigns for education and public awareness-building can support the promotion of the advantages of green concrete and boost consumer demand for it. These can involve media campaigns, community outreach activities, and instructional programs for students (Serdyukov, 2017).

- Invest in research and development: The performance and economics of green concrete can be enhanced with more research and development. This can involve looking into new products, processes, and technology that can lessen the negative effects of construction on the environment (Sivakrishna et al., 2020).

- Promote multi-industry collaboration: The promotion of the usage of green concrete may be aided by cooperation between the building industry and other sectors of the economy. For instance, working with the waste management sector to promote the use of recycled aggregates in concrete is a good idea (Heincke et al., 2023).

- Perform more elaborate life cycle sustainability assessments: An evaluation of the life cycle of green concrete can help pinpoint areas for development and show how utilising green concrete is advantageous from both an economic and environmental standpoint (Van Den Heede and De Belie, 2012).

- Focus more on public-private partnerships: By combining the resources and skills of the public and commercial sectors, public-private partnerships may support the use of green concrete. Partnerships in the building industry between private businesses as well as those between governments are examples of this (Carbonara and Pellegrino, 2020).

There is no definite solution or strategy that can offer one hundred per cent guarantee of success as each of the aforementioned suggestions come with certain advantages and limitations highly dependent on local context, availability of resources, market trends, sustainability goals and so on. It may also be effective to focus on specific areas or regions where the need and demand for sustainable construction materials are high, and where policies and regulations are supportive of their implementation (Guest, 2021).

In the end, it is likely that a mix of varied approaches that are suited to particular settings and demands will be most successful in overcoming the difficulties and restrictions of implementing green concrete. Even focusing on the Portland cement reduction for the time being is a great change, and it counts as valuable for the sustainable development of the built environment (Belton, 2021).

2.4 Strategy-making: Integrating Innovations

According to Seaden et al. (2003), the process of identifying and prioritising goals, creating and implementing strategies, and allocating resources in a coordinated and integrated manner to achieve those goals is known as strategy-making in the construction industry. It entails examining the existing situation, evaluating the internal and external elements that have an impact on the organisation, and developing a success plan.

2.4.1 The Importance of Strategy-making in Constructions

Strategy is highly relevant for a company, as it is determining the direction and the overall goals of a business entity or project (Cote, 2020). It helps to focus efficiently the efforts and resources on the most relevant activities, align the team members with the other stakeholders involved on a common mission (Charlott, 2022), be flexible in a volatile market based on market needs, gain advantages in terms of competitivity and improve performance, efficiency, and profitability (Carey, 2023). On top of that, Charlott (2022) states that strategy formulation in the construction business can also aid in the identification and incorporation of innovations that can improve value proposition and sustainability.

As highlighted in Subchapter 2.3.2, by fostering change and generating new prospects for expansion, productivity, and sustainability, innovation plays a significant part in reshaping the construction sector. The way construction projects are planned, carried out, and maintained has the potential to change as a result of advances in materials, technologies, and procedures, which would enhance quality, safety, and productivity (Abusalah and Tait, 2018). Innovation can also assist in addressing some of the major issues that the construction industry is currently dealing with, including lowering waste and emissions, raising energy efficiency, and enhancing the resilience of infrastructure and buildings to both natural and man-made threats. The construction sector can maintain its competitiveness and adapt to the changing needs of society and the environment by using innovative methods and solutions (Tangkar and Arditi, 2004).

When it comes to the integration of green concrete in the construction industry, as explained in Chapter 2.3, the process presents a great difficulty with numerous challenges and limitations. The lack of awareness and understanding among the construction specialists, higher initial costs, regional supply chain issues, technical uncertainty and the conservative attitude increase the complexity of adoption resulting in uncertain timelines and no practical results.

On the other hand, there is also an opportunistic frame that can be identified for the implementation of green concrete solutions. As the humanity is pressured by the effects of climate change and limited raw resources, there is an increasing demand for more sustainable materials, governments are becoming more open to incentivise the use of sustainable solutions (Hundertmark et al., 2022), the multitude of green concrete variations become more popular making them more cost-efficient and largely available (Software, 2020) and also the public perception of the companies that "go green" is often seen positively with great reputation (Hundertmark et al., 2022).

2.4.2 Strategy-development: Influencing Factors

To develop strategies for the integration of green concrete in real-life applications, there are several factors that need to be considered, balancing the existing challenges and the possible opportunities. According to the papers of Suhendro (2014); Sivakrishna et al. (2020); Liew et al. (2017) the market demand, technological readiness, economic feasibility, environmental impact, regulatory compliance and overall collaboration are some of the main factors that need to be included in the decision-making process.

Prior to establishing strategies, the amount of demand for environmentally friendly building materials, such as green concrete, should be evaluated. It is important to consider both existing and future demand when assessing the market need for green concrete. It is also important to take into account how ready the building sector is to implement green concrete developments, known as TRL or Technological Readiness Level. Therefore, an evaluation of variables including the accessibility of resources, tools, and skilled labour is required.

The economic viability is also relevant it this context. It is important to compare the price of green concrete to that of conventional building materials for manufacture, installation, and maintenance. Additionally, green concrete developments should be evaluated in terms of their environmental impact. Carbon emissions, energy consumption, and waste reduction should all be considered.

As for regulatory compliance, green concrete technologies should be examined in terms of regulatory compliance criteria. All legal or regulatory obligations should be identified and included into strategy formulation.

To simplify this initial process, a SWOT analysis can be conducted to observe the Strengths, Weaknesses, Opportunities, and Threats that come along with the innovative idea. This method can be used to assess the strategic position of a variety of organisations and is intended for use in the early phases of decision-making processes (Caves, 2004). It aims to pinpoint the internal and external elements that are advantageous and detrimental to attaining the goals of the project or enterprise. In order to make a SWOT analysis helpful and discover their competitive advantage, users frequently ask and respond to questions to provide meaningful information for each area (Gürel and Tat, 2017).

In the end, cooperation and collaboration among stakeholders such as architects, engineers, contractors, suppliers, and policymakers is essential for the successful implementation of green concrete developments. Mechanisms for fostering cooperation and collaboration among stakeholders should be included in the strategies.

2.4.3 Integration of Innovations

Ozorhon et al. (2014) states that the integration of an innovation, regardless of the types of innovation that might be, is a process. This process entails binding together new ideologies and technologies in order to create something completely new or improve something that already exists. All the challenges presented in Chapter 2.3 together with the influencing factors in terms of decision-making, explained in Subchapter 2.4.2, are part of this process.

In the book *Relentless Growth* by Meyer (1998), the path of an innovation towards practical application is described by two simple models, the Traditional Linear Model, and The Flexible Innovation Model, see Figure 2.4 and Figure 2.5. The Traditional Linear Model assumes that an innovative idea to reach maturity follows a defined sequence of steps, but if analysed in depth, the efficiency of this approach is low due to lack of feedback loops, inconsistencies, and poor room for adjustments (Chirumalla, 2017). The Flexible Innovation Model enables overlapping delivery phases and allows for flexibility in design to incorporate new technology, which is handy in the case of green concrete due to the large number of mixtures possibilities. While it works well in a dynamic business environment, it lacks guidance on controlling changes, and there is no predefined systematic approach (Xichen et al., 2021).

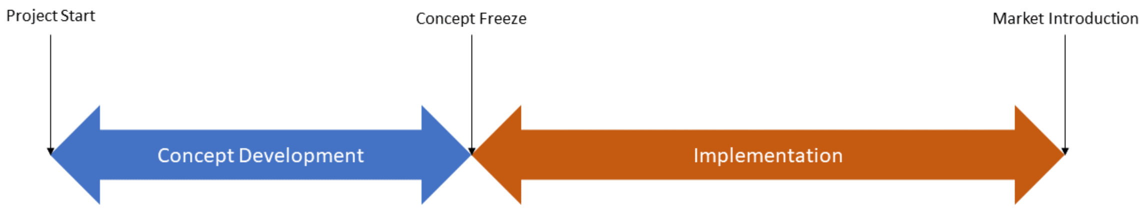

Figure 2.4: Traditional Linear Model; Adapted from Meyer (1998)

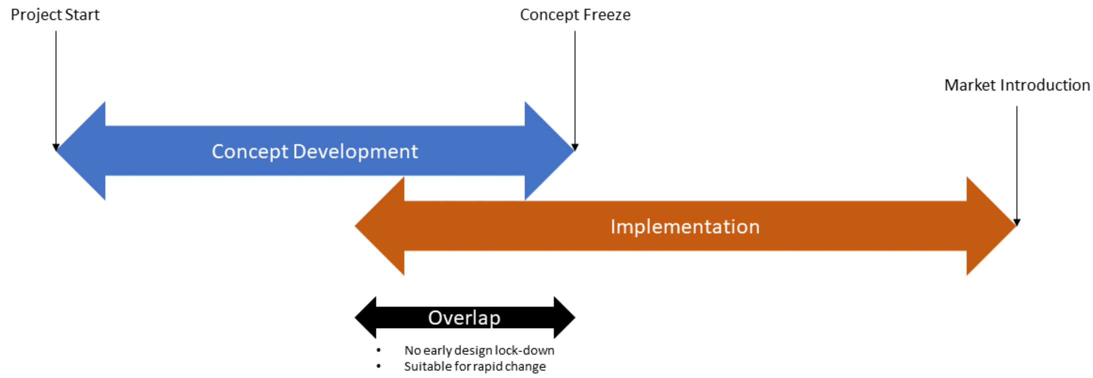

Figure 2.5: Flexible Model; Adapted from Meyer (1998)

The integration of innovations in the construction industry is highly dependent on the specific aspects of the product, project, and process (Duodu and Rowlinson, 2021; Abusalah and Tait, 2018). The current literature offers a wide range of approaches and steps for implementing innovation and identifying relevant variables. Lawlor (2019) suggests involving executive leadership, promoting cross-disciplinary collaboration, developing detailed innovation process plans, and prioritising end-users. Molloy (2019) outlines five key steps for implementing innovation: discovery, ideation, prototyping, testing, and launching. Livescault (2022) describes a seven-step process, including creating a strategic direction, finding inspiration, ideation, developing a proof of concept, piloting, rolling out and producing, and finally, using measurement tools and gathering feedback.

Implementing green concrete solutions follows a unique pattern, as financial concerns, lack of knowledge and awareness, and conservative attitudes can impede the process, as discussed in Subchapter 2.3.2. By focusing on education, collaboration, incentives, and research, these issues can be addressed, and leveraging technology to support innovation integration may be essential.

Technology plays a critical role in incorporating innovation in construction, assisting with the creation, implementation, and management of new technologies and processes (Ahmad et al., 1995). For example, BIM technology can be used to visualise and analyse construction projects, fostering more effective collaboration among stakeholders. Additionally, digital technologies like sensors and automation can enhance the efficiency and quality of construction processes while reducing waste and costs (Ellis, 2022). Technology can also facilitate the adoption of innovative materials such as green concrete by providing tools for performance testing and monitoring and optimising design and production. In summary, technology can significantly support innovation integration in construction by enabling new ways of working, increasing productivity, and promoting sustainability (Galindo, 2021).

In conclusion, implementing green concrete technologies or other innovations in the construction industry requires a comprehensive strategy that considers scalability, adaptability, and cost-effectiveness. The development of novel materials and technologies, such as carbon capture and utilisation, self-healing concrete, and 3D printing, as discussed in Subchapter 2.3.1, will be future avenues for innovation integration in the industry. By prioritising innovation integration, the construction industry can make substantial progress toward a more sustainable future.

Chapter 3

Research Design

3.1 Research Scope

The research scope of this graduation project is centred around the implementation of green concrete in construction projects to promote and reach sustainability, taking into consideration the challenges that interfere with the adoption of innovations. The research questions are linked to the definition and significance of green concrete, the most common barriers and challenges faced by construction professionals, the key factors that influence the decision to adopt green concrete solutions, and the best practices and strategies for integrating green concrete solutions into construction projects. The research incorporates a literature review, an online survey, and semi-structured interviews with specialists from the construction industry to gain a comprehensive understanding of the status of green concrete in the sector and to identify potential solutions and strategies for promoting its adoption.

3.2 Methodology

As previously mentioned, this graduation project is conducted in partnership, and with the support of the company Witteveen+Bos. Throughout this research, they provided professional guidance, real-life experience insights, and access to valuable information to successfully deliver the graduation project. Witteveen+Bos is a well-established Dutch engineering and consulting firm that provides services for water, infrastructure, spatial development, the environment, and construction on a national and international scale. With over 1400 employees, the company focuses primarily on complex projects requiring superior expertise and an integrated approach. Short communication channels with clients are crucial to their work. They maintain international offices in Belgium, Indonesia, Kazakhstan, Latvia, Russia, Singapore, and Vietnam in addition to their headquarters in the Netherlands.

To give an answer to the main research question, this graduation project relies on a mixed methodology, incorporating both quantitative and qualitative data. Given the complexity of the researched topic, these two methods combined come with the advantage of providing a complete, detailed picture of the studied issue (Cotten et al., 1999). Triangulating the data obtained via the quantitative sources with the qualitative interpretation allows a greater variety of perspectives to tackle the addressed problem of implementing green concrete solutions in construction projects.

As the main research question is backed up by the four sub-research questions, to simplify the research process, a division is created in terms of data sources, sub-research questions and analysis as depicted in Figure 3.1. The literature review and survey are employed to address sub-research questions 1 and 2 to create a robust understanding of green concrete in the construction industry. The literature review establishes a solid knowledge base and uncovers gaps, while the survey provides real-world insights from construction professionals. This combination offers a comprehensive, practical understanding of the definition, significance, and challenges associated with green concrete, ensuring the research findings are well-grounded and informed by practical experience. Using literature review and semi-structured interviews for the sub-research questions 3 and 4 is ideal because they combine theoretical and practical perspectives on green concrete adoption and integration. Literature review delves into existing research to reveal influencing factors and strategies, while interviews with industry professionals uncover real-world experiences and lessons. This balanced approach ensures comprehensive understanding, guiding effective green concrete implementation in construction projects.

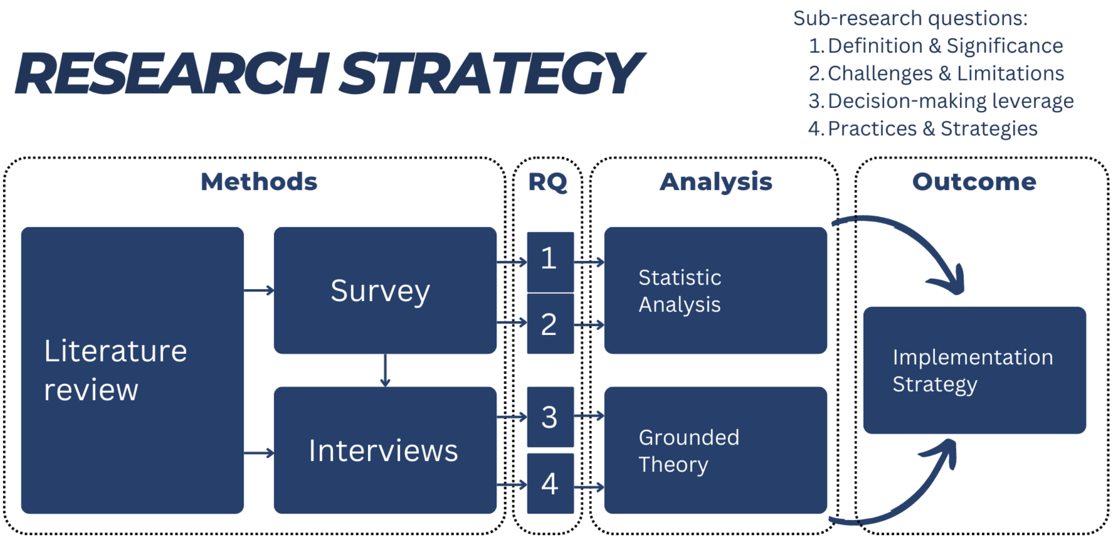

Figure 3.1: Research Strategy; Source: Author

3.2.1 Literature Review

The literature review is a crucial component of the methodology used in this study, since it provides a thorough overview of the research problem and establishes the framework for the research questions. The literature study will identify and analyse any previous research on green concrete and its potential to improve sustainability in the building sector. This calls for a thorough search of scholarly databases, specialised journals, and other relevant sources, with a focus on current and reliable articles.

The literature review chapter is organised in line with the research topics and offer an overview of the key ideas, philosophies, and practises around the use of green concrete solutions in construction projects. This will include an extensive explanation of the concept itself, an overview of the environmental, social and economic impacts throughout its life-cycle, strengths and weaknesses of various innovations and technologies in promoting sustainability and also possible challenges and limitations that can impede the wide spread of green concrete.

The literature review also highlights the importance of green concrete for the construction sector, and it explores the procedure for integrating innovation and the part that technology plays in promoting the use of green concrete in building.

Overall, the chapter on the literature review lays the groundwork for future study and practical uses of green concrete in the building sector.

3.2.2 Online Survey

Based on the research strategy, see Figure 3.1, the survey, together with the literature review, reflects upon the first two sub-research questions. These two questions, aim to collect information on what green concrete is also what are the challenges the construction professionals are facing when trying to implement new concrete solutions.

The first sub-research question, "What is the definition and significance of green concrete in the construction industry, considering its potential to promote sustainability?" seeks to explore the understanding, familiarity and overall general feeling about green concrete. Whereas, the second sub-research question, "What are the most common barriers and challenges faced by construction professionals when implementing green concrete solutions in their projects, and how can these be addressed effectively?" concentrates on identifying the obstacles faced by individuals in real-world applications.

The target population for this survey is represented by the employees of Witteveen+Bos. The consultants, in this scenario, act construction professionals with relevant knowledge on the actual status of the industry. In many cases, consultants are enablers of implementing innovations in the sector, therefore their views and opinions are highly relevant (McKinsey, 2018). In terms of sample size, the survey was sent out to a number of 320 individuals within the company's network in a time frame of about 2 weeks. The questionnaire was intentionally sent to a total number of 11 groups known as PMCs, therefore the respondents have different fields of expertise. Despite the difference in terms of expertise, the PMCs were selected, considering "concrete" as a common factor in interdisciplinary projects. A detailed explanation of the samples size is given in Table 4.1.

To collect the data for the survey, Microsoft Forms was used. This online tool safely stored the data on the company's server and assured that only employees connected to the private network had access to the survey. The identity of the participants was kept under anonymity, except for the individuals that agreed to further discuss in an interview the subject of this research project. In the description of the survey, the participants were informed that the data is confidential, it will be used strictly for research purposes and only the corresponding researcher has access to the database.

The questionnaire consisted of 17 questions, in English language, specially created to observe multiple factors regarding the concept of green concrete. A list of question with additional explanations are given in the following paragraph. A detailed view of the survey can be seen in Appendix A.

Online Survey List of Questions

1. What is your PMC? (PMC is an internal organisational structure of the company which describes a larger group containing multiple subgroups) - Open field - Observing the field of expertise.
2. On a scale from 0 to 10, how familiar are you with the concept of Green Concrete? - 0 to 10 scale - Familiarity with the concept of GC.
3. How would you define Green Concrete with only 3 keywords - Open field - Understanding of the concert of Green Concrete.
4. Do you think that GC is important for the construction industry? - Yes, No, Maybe single choice - Personal professional reflection upon importance.
5. How important would you say that Green Concrete is? - 0 to 10 scale - Degree of importance.
6. How open would you say that the construction industry is in regard to new materials? - 0 to 10 scale - Perception upon importance.
7. Do you consider that the industry is willing to adopt GC solutions? - 0 to 10 scale - Adoption willingness of the industry.
8. Would you consider that Green Concrete is promoted sufficiently in current practices? - 0 to 10 scale - Promotion levels in the market.
9. Did you have any opportunity to work with GC or other innovative materials? - Yes, No single choice - checking on prior experiences
10. Would you like to work on a project that involves Green Concrete or other innovative material? (If the answer was No at Q9) - Yes, No, Maybe single choice - Checking on interest and willingness.
11. With what type of Green Concrete or other innovative material did you work - Open field - To map out solutions.
12. What were the main challenges when working with Green Concrete or other innovative material? - Open field - To map out challenges.
13. How would you prioritise the 3 given aspects of sustainability when it comes to Green Concrete? (top being the most important and bottom the least important) - Priority between Environment, Society, Economy - Observing consideration in decision-making.
14. From literature, 10 most common barriers to innovation were listed to assess impact. - 1 to 5 scale - Observing impact.
15. How likely are you to recommend Green Concrete as a reliable construction solution? - 0 to 10 scale - Future prospects
16. What is your main concern regarding Green Concrete? - Open field - Observing concerns.
17. Would you be willing to possibly discuss this topic further in an interview? - Yes, No single choice - Possible candidates for interviews.

As depicted in Figure 3.2, the 0 to 10 scale was given to cover a larger variety of responses. It allows participants to rate their response on a scale of 0 to 10, where 0 represents the lowest level of agreement or satisfaction and 10 represents the highest level.

A good way to interpret the 0 to 10 scale is to consider the midpoint, which is 5. Ratings above 5 indicate a positive response, while ratings below 5 indicate a negative response. A rating of 10 indicates strong agreement or satisfaction, while a rating of 0 indicates strong disagreement or dissatisfaction (Toor, 2022). Additionally, the distribution of responses across the scale can provide insights into the range and variability of responses.

Figure 3.2: Zero to ten scale interpretation; Source: Author

The 1 to 5 scale was used in a single instance to describe the impact on the implementation of green concrete of the 10 most common barriers to innovation. This scale is a Likert scale which commonly is used in social sciences, like for example measurements in terms of opinions or attitudes (Likert, 1932). Illustration 3.3 explains the meaning of each score from 1 to 5.

Figure 3.3: Likert scale explanation; Source: Author

All the data collected was exported in an Excel file and verified for incomplete or suspicious answers. After the cleaning process, the data was statistically analysed with the help of SPSS software. This tool was designed by IBM company and the main purpose of it is to help with advanced statistical analysis of different type of data.

A descriptive statistical analysis was performed in SPSS in order to describe the sample in detail, followed by a factor analysis and a relative importance index. The factor analysis was chosen due to the large number of variables resulted from the survey, thus a reduction of the number of variables that describe most of the variance was necessary. The relative Importance Index (RII) was used to describe what is the main challenge the employees of the company believe it is when it comes to the implementation of green concrete. The results of these analyses are explained in detail in the Chapter 4.

As disclaimer, there are potential limitations with respect to the generalisability of the results. As the survey was conducted only at the company's internal level, therefore some bias could be the case as the data sample might not represent the entire population accurately, lack of honesty when filling in the survey due to socially desirable responses, misunderstanding or external factors, as the real status of the industry. The possible limitations are considered in the interpretation of the results and for the development of possible recommendations.

3.2.3 Semi-structured Interviews

To tackle the subjectivity of this research and to gather qualitative data, semi-structured interviews were used as an additional research method for this graduation project. This method describes a type of interview in which the questions asked are not in a specific order, but belong to a predetermined theme. The core idea of this qualitative research method is to engage the participant and corresponding researcher into dialogue, by introducing follow-up questions, comments and additional discussions (George, 2022).

As depicted in Figure 3.1, the semi-structured interviews in combination with the literature review approach the third and fourth sub-research questions.

“What are the key factors that influence the decision to adopt green concrete solutions in construction projects, and how can these be leveraged to promote the widespread implementation of these solutions?”. This issue is crucial because knowing what influences the use of green concrete can help pinpoint adoption obstacles and create solutions for them. In-depth knowledge is obtained from subject-matter authorities through semi-structured interviews, enabling a thorough investigation of the decision-making process.

“What are the best practices and strategies for integrating green concrete solutions into the design and construction process, ensuring that they are seamlessly integrated into the project and meet the required performance standards?”. This question makes a direct call onto the current process of implementing green concrete in construction projects. It relies on exemplification, and it refers to distinct stages of a project, design, and construction which gives the interview participant the freedom to elaborate. The question also includes a quality assurance indicator to help explore even further the issue at hand.

As mentioned before, the semi-structured interviews allow flexibility in terms of questioning and free speech. Nonetheless, a list of questions was drafted prior to the interview sessions in order to guide both the participant and corresponding researcher. The list consists of 10 main questions with additional sub-questions, and formulated as follows:

Semi-structured Interviews List of Questions

1. What is your profession?
    - (a) Where do you work?
    - (b) What is your job title?
    - (c) How many years of experience do you have?
2. How do you see sustainability in construction, and what do you think can be done to achieve it?
3. How would you describe innovation in the construction sector, generally speaking?
4. Who do you think that has the most power to implement innovations from all the possible stakeholders involved in the construction industry?
    - (a) If you would be in that power position, what would be one thing that you would do to help innovations become practical applications?
5. How would you describe Green Concrete with your own words?
6. What are your thoughts on the state of green concrete in the industry as of today?
7. Is Green Concrete of any importance to the current construction market?
    - (a) Why?
8. Do you believe green concrete should always be used in new buildings, or are there occasions where it is not an appropriate choice?
9. What are some challenges that can occur by using green concrete in construction?
    - (a) Examples?
    - (b) How did you experience the challenges in your project/organisation?
    - (c) Any similar instances?
    - (d) Some other challenges?
10. What are some of the most innovative and exciting materials you have worked with in your career?
    - (a) What kind of material?
    - (b) What kind of project?
    - (c) What did you like about that new material?
    - (d) What did you not like about that new material?
    - (e) What were the challenges you faced?
    - (f) How were those issues solved?
    - (g) Where do you think those issues came from?

The questions were created in such manner to cover an extensive area of interest related to the topic of GC and real-life experience with GC. The next paragraphs explain the reasoning for each question or set of questions.

The first set of questions gathers information about the interviewee in terms of profession and experience. Having this information provides further context onto the following questions.

Second question explores the perception of individuals about sustainability in the construction sector, and it is also aimed to collect possible solutions on how to achieve it.

The third question introduces the interviewee into the main idea of this research, innovation. In this case, GC is the innovation, but a more generalised manner is selected initially to check how it is exactly perceived by each individual.

Question number four is intended to investigate the stakeholder relationships and power dynamics in the building sector. This can aid in understanding the interviewee's viewpoint on who has the greatest influence on putting innovations into practise and their concepts for doing so.

The fifth, sixth, seventh, eight, and ninth questions narrows down the topic and is specifically referred to the main subject of this research, GC. These questions are intended to find out the current status of GC in the current market, its importance, its use for practical applications and general challenges that can occur while using this new material.

The last question explores the individuals experience with any innovative solutions in order to identify possible solutions that can help with the implementation process of GC.

For this graduation project, a total number of 19 interviews were conducted with specialists within the construction sector. The interview sessions were led in a hybrid manner (online sessions and in-person meetings) in order to increase efficiency and shorten then time allocated for this stage of the research project. A time frame of 60 minutes was allocated for each session, but as seen in Table 3.1 there is a variable duration depending on multiple factors, as type of meeting, online calls lasted less than in-person meetings, expertise of the participants, and also years of experience; younger participants has shorter answers, but they were more open to the idea of GC. The names of the participants are undisclosed due to privacy matters, and the data resulted from the interviews is processed in such manner that it is non-identifiable and non-traceable.

Table 3.1 gives an overview on the number of interviews, types of stakeholders involved, their expertise, interview setting and also duration. In total 19 interviews were conducted with various specialists across the construction industry, out of which 14 individuals work for Witteveen+Bos and 5 belong to different organisations relevant to the Dutch construction market. The semi-structured interviews allowed an open and flexible approach to collect data for the given purpose of this graduation project, and the variety in terms of expertise helped draw a realistic status of the industry as of the time being.

In total 807 minutes worth of recording resulted from the 19 interviews, which can be translated in 13 hours. The average number of pages transcribed per individual sits around 14 pages, which gave about 266 pages of data in text format to be reviewed, processed and analysed in a qualitative manner.

ID	Participant code	Expertise	Interview set-up	Duration (min)
1	WB_1	Circular and bio-based solutions	IRL	45
2	WB_2	Circular and bio-based solutions	IRL	55
3	WB_3	Replacement/renovation of art works	IRL	35
4	WB_4	Digital construction	VM	27
5	WB_5	Circular and bio-based solutions	IRL	55
6	WB_6	Life cycle management	IRL	50
7	WB_7	Buildings	IRL	45
8	WB_8	Life cycle management	VM	27
9	WB_9	Buildings	VM	35
10	WB_10	Buildings	VM	50
11	WB_11	Relational Contracting	IRL	65
12	WB_12	Replacement/renovation of art works	IRL	50
13	WB_13	Infrastructure constructions	VM	23
14	WB_14	Energy transition	IRL	57
15	EXT_1	Circular/sustainable transitions	VM	30
16	EXT_2	Innovative procurement	VM	30
17	EXT_3	Innovation Development	VM	54
18	EXT_4	Civil constructions	VM	26
19	EXT_5	Concrete technology	VM	53

Table 3.1: Detailed view of the interviews

Prior to conducting the interviews, each participant received via email an official invitation to the discussion. The invitation, see Appendix E, included a description of the interview, including scope, organisational matters and the list of questions to help the participants prepare in advance. Also, all the participants were informed beforehand that the interviews are recorded and transcribed accordingly for qualitative analysis.

As established by the TU Delft Human Research Ethics Committee and the interview participants, the identity of individuals must remain undisclosed. Therefore, the expertise section from Table 3.1 describes a broad area of expertise. To be noted, lower and higher management within the company participated in this interview. Therefore, some quotations in Chapter 5 will clarify the function in order to highlight an important idea without compromising the identity of the individual. For the external parties included in the research, functions as TU Delft professor, Rijkswaterstaat senior advisor and technical advisor, civil constructions advisor, from the municipality of Fryslan, and representative of Cementbouw, with extensive affiliations in the industry, provided qualitative data.

The interview participants are separated by codes as well as the interview set-up, see Table 3.1. The codes denoted with "WB" represent people working for Witteveen+Bos, whereas the code "EXT" refers to individuals from outside the company. The number attributed to each code only serves as a list indicator. For the interview set-up, two codes are present. IRL describes the interview as being conducted in "In Real Life" and VM, which stands for "Virtual Meeting".

The IRL meetings took place at Witteveen+Bos offices across the Netherlands, like Utrecht, Amsterdam, Rotterdam, etc., depending on the availability of each individual. For the VM interviews, Microsoft Teams was used, serving also as a recording tool for later review.

The IRL meeting were recorded with a voice-recording app on a cellular device, whereas VM took advantage of the Microsoft Teams' meeting recording function. The resulting audio file from the IRL meeting was directly uploaded to Microsoft Word One Drive version for transcription. Since Microsoft Teams is only producing video recordings, the resulting files from the VM interviews had to be initially converted from video to audio before uploading them to Microsoft Word.

The transcripts made via the Microsoft Word application had to undergo a thorough review due to the limited capacity of the software to transcribe 100% correctly. Other factors that influence the ability of the software to properly transcribe are represented by the fact that none of the participants were native English speakers, different accents, speaking volume, diction, recording environment and uncoordinated speaking order between the researcher and participants.

To analyse the data retrieved from the interview sessions, the grounded theory method is used. In the social sciences, grounded theory is a research process used to construct theory that is "grounded" in evidence. The objective of grounded theory is to produce a theory that is strongly connected to, or "grounded" in, the study data (Martin and Turner, 1986). The created theory is neither predetermined nor imposed on the data; rather, it develops from the data via a process of ongoing comparison and analysis. The purpose of grounded theory in qualitative research is to explain complicated social processes in a rich and nuanced manner. This process is used to comprehend the significance of the data and uncover its patterns, themes, and linkages. As new data are obtained, the researcher continuously revises and refines the emerging theory. Grounded theory is a flexible and adaptable method that permits researchers to investigate complex and dynamic phenomena in a systematic and rigorous manner (Strauss and Corbin, 1994).

The semi-structured interviews are analysed in ATLAS.ti by means of Qualitative Content Analysis approach. Assigning sections of the material to the major and subcategories of the coding frame is one of the processes in the systematic process known as qualitative content analysis (Flick, 2018). ATLAS.ti is a software specially programmed for qualitative analysis of data. Its capacities include coding directly in the transcripts, making notes and grouping the codes in clusters. It is an useful tool in terms of visualising the data as it is able to generate charts and diagrams which help with data-interpretation. The entire process of analysis in ATLAS.ti includes three distinct steps which entail data preparation in terms of transcripts review be means of grammatical corrections; data organisation by structuring the content and making in-text quotations for future coding and lastly, data interpretation based on prior theoretical knowledge.

Chapter 4

Online Survey Results

This chapter presents the results of the online survey conducted at Witteveen+Bos regarding the implementation of green concrete solutions in construction projects. As mentioned in Chapter 3, this research relies on both quantitative and qualitative data. While the semi-structured interviews are purely qualitative based, the survey provides both types of data.

To tackle the first two sub-research questions, see Chapter 1, Section 1.4, the questionnaire was specially designed to touch upon multiple subjects as described in Subsection 3.2.2. Each of the question will be shortly statistically described in an initial assessment, followed by the Factor Analysis and Relative Importance Index.

Out of the 320 contacts, 85 responses were considered valid and included in the analysis. The response rate for this particular survey is deemed relevant since the population size within the company is smaller compared to the general population (Toor, 2022). Additionally, since the respondents work in the same environment and share the same company culture, they are likely to have similar characteristics. As a result, a sample size of 85 responses out of the total population of 320 employees is considered reliable for obtaining accurate information. A detailed view of the number of participants and their department within the company is given in Table 4.1.

ID	PMC	Frequency
1	Buildings	15
2	Circular Bio-based Solutions	5
3	Deltas, Coasts Rivers	1
4	Drinking water and process water	3
5	Harbour Constructions and Design	5
6	Infrastructure Mobility	6
7	Infrastructure Constructions	10
8	Life Cycle Management	14
9	Relational Contracting	2
10	Replacement and renovation of works of art	13
11	Underground Infrastructure	11
	Total	85

Table 4.1: Survey respondents per department

As explained in Section 1.4, each question or set of questions described one variable which are further on explained individually.

4.1 Descriptive Statistical Analysis

4.1.1 Familiarity with the Concept of Green Concrete

"On a scale from 0 to 10, how familiar are you with the concept of Green Concrete?"

The bar chart in Figure 4.1 shows the distribution of responses to the corresponding question. The Figure 4.1 represents a visual simplification of the data provided in Table B.1 from Appendix B which is exported from SPSS software.

From the graph, it can be observed that the majority of the responses fall in the range of 2 to 7, with the highest frequency of 15 responses at a rating of 2. The frequency decreases gradually as the rating moves away from 2 in either direction, with the least frequency of 0 responses at a rating of 10.

The graph has a slightly negative skewness, indicating that the responses are somewhat evenly distributed, with more responses towards the lower end of the scale. The kurtosis is slightly flat, indicating a relatively uniform distribution of responses.

In conclusion, the graph shows that there is a varying level of familiarity with Green Concrete among the respondents, with a majority being moderately familiar with the concept. The graph also indicates that there is room for improvement in terms of raising awareness and educating people about the benefits and applications of Green Concrete.

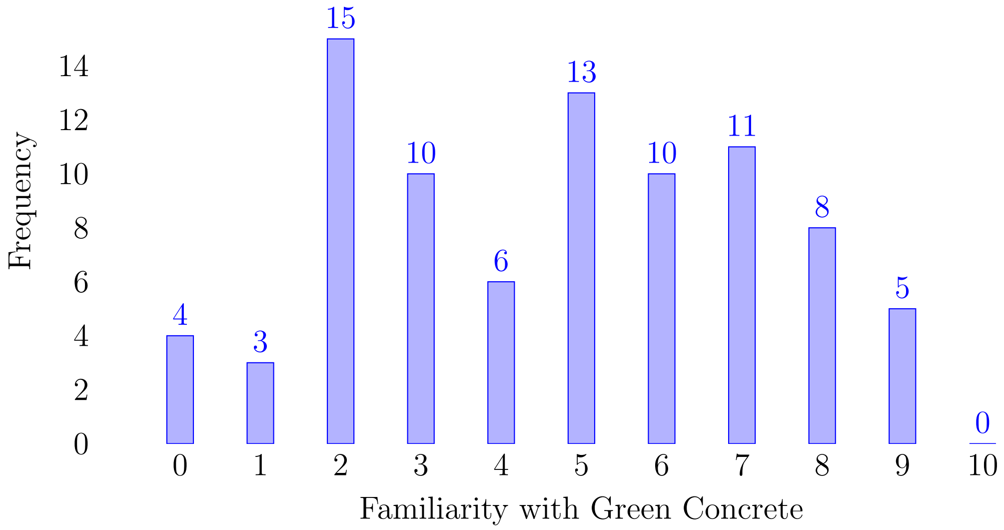

Figure 4.1: Familiarity with Green Concrete - Frequency of Scores; Source: Author

4.1.2 Definition of Green Concrete in key-words

"How would you define Green Concrete with only 3 words?"

The qualitative data resulted from these questions is grouped in the word-cloud illustrated in Figure 4.2. Based on the frequency a word was given as a response, the size of the word-cloud was increased. A detailed list with the key-words describing the concept of GC can be found in Annex C, together with the frequency of appearance. These terms imply that green concrete is seen as a long-lasting and environmentally responsible building material that attempts to lower CO2 emissions, make use of recyclable materials, and incorporate substitute materials like geopolymers. Additionally, it highlights how crucial carbon neutrality is when discussing green concrete.

Figure 4.2: Green Concrete Definition in key-words; Source: Author

4.1.3 The Importance of Green Concrete in the Construction Industry

"Do you think that Green Concrete is important for the Construction Industry?"
"How important would you say that Green Concrete is?"

When asked about the relevance of GC for the construction sector, 80% of the respondents believe that GC is important, 18% or 16 individuals are somewhere in between and 1 person stated that GC is not relevant, see Table B.2 and Figure 4.3.

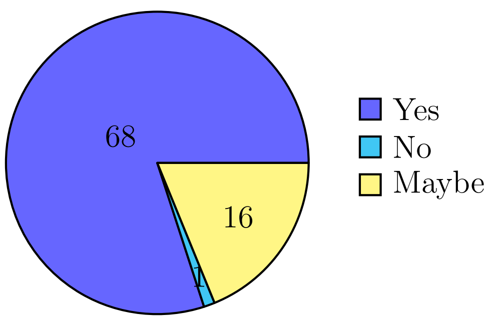

Figure 4.3: Relevance of GC; Source: Author

In order to assess the degree of importance, the respondents were asked to score from a scale from 0 to 10 how much they believed in that importance of the GC for the industry.

From Table B.3, the frequency of scores is illustrated for better visualisation in Figure 4.4 with scores ranging from 3 to 10. The highest frequency of responses was for a score of 8, with 23 participants (27.1%) selecting this score. Scores of 7 and 9 were also selected frequently, with 14 participants (16.5%) selecting a score of 7 and 17 participants (20%) selecting a score of 9. The lowest frequency of responses was for scores of 3 and 4, with only 1 participant (1.2%) selecting each of these scores.

It can be stated that overall the respondents consider that GC is quite relevant for the industry, and it is of high importance, considering the distribution of the graph towards the right side of the scale.

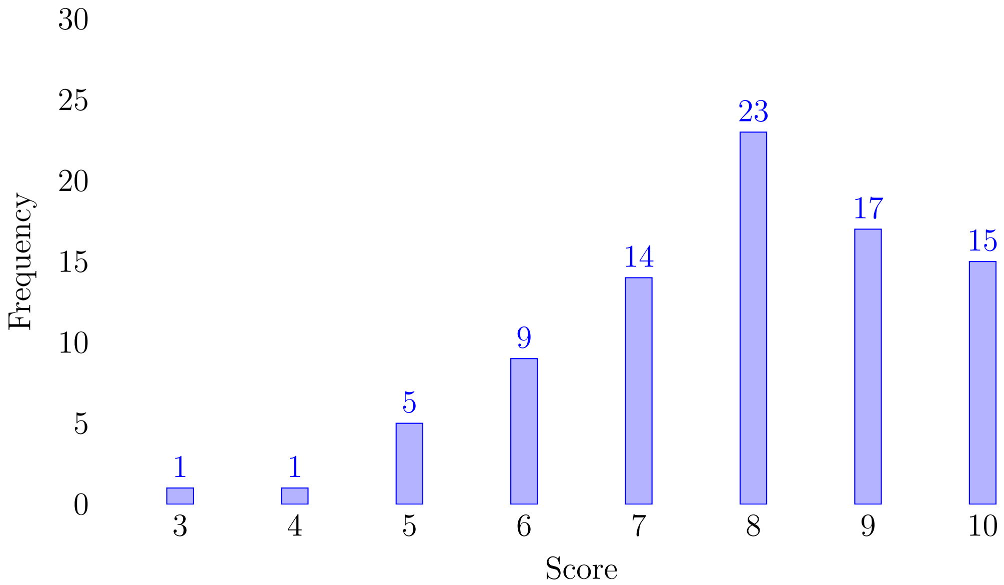

Figure 4.4: Degree of importance for GC; Source: Author

4.1.4 The Industry's Openness, Willingness and Promoting Skills

"How open would you say that the construction industry is in regard to new materials?"
"Do you consider that the industry is willing to adopt Green Concrete solutions?"
"Would you consider that Green Concrete is promoted sufficiently in current practices?"

Figure 4.5 provides information about the frequency of responses related to openness of the construction industry to new materials. The survey responses only scored 10 of the 11 possibilities, as score 0 was not assigned by any participant. The survey responses are presented as a frequency count, a percentage, a valid percentage, and a cumulative percentage in Table B.4.

The most common response was in category 6, with a frequency count of 24 and a valid percentage of 28.2%. Categories 3 and 4 were the second and third most common responses, with frequency counts of 15 and 11, respectively. The neutral category received six responses, accounting for 7.1% of the total responses.

Overall, the results suggest that the industry is somehow open to new materials, with the majority of responses falling within the 3 to 9 interval of response categories.

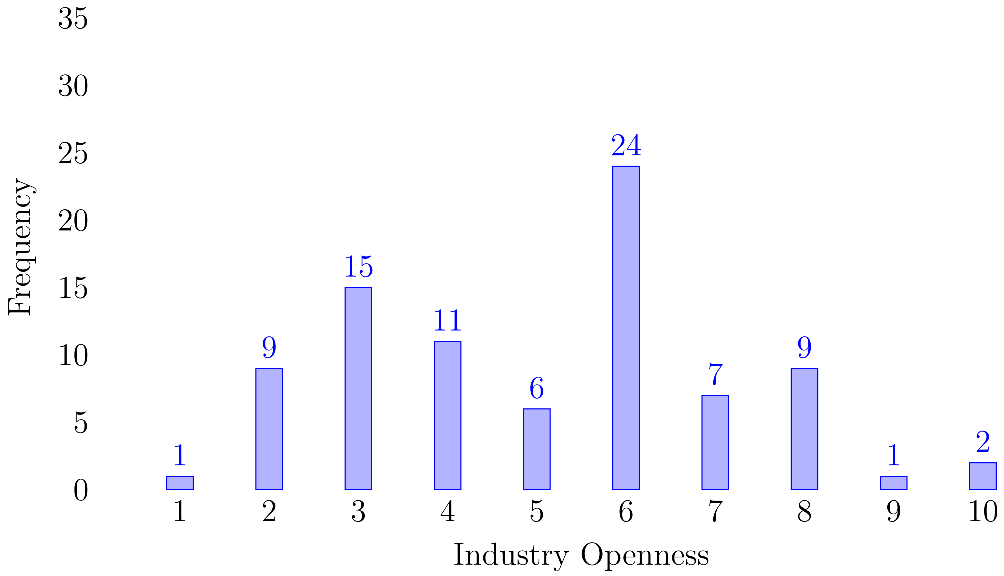

Figure 4.5: Industry Openness to new materials

The graph in Figure 4.6 shows the frequency of industry acceptance of GC, with the x-axis representing the level of acceptance on a scale from 0 to 10 and the y-axis representing the frequency of responses. The graph is a histogram that shows a positively skewed distribution, with the majority of responses concentrated in the middle of the scale (between 5 and 8). The highest frequency is at the level of 6, indicating that the industry is somewhat willing to adopt GC.

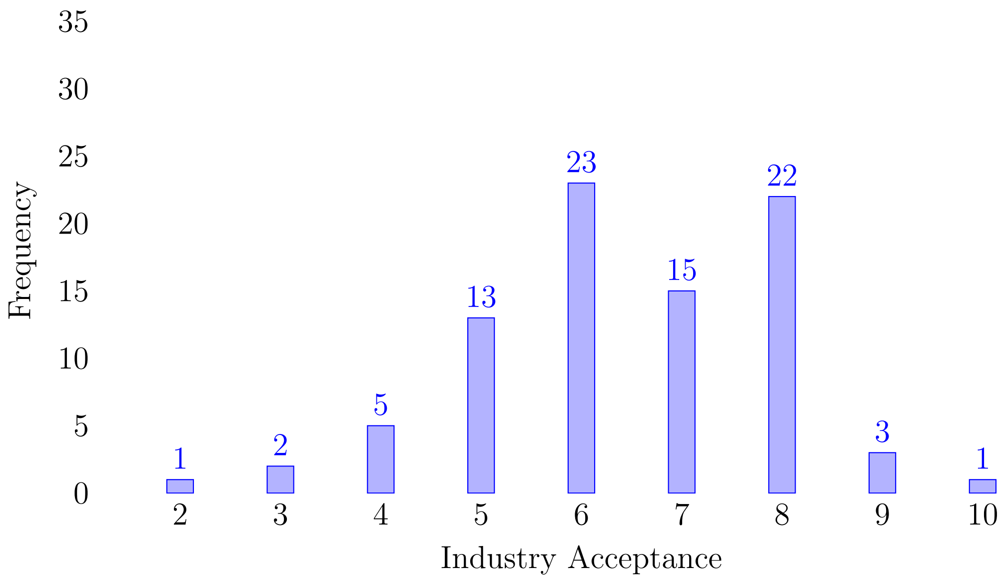

Figure 4.6: Industry Willingness to adopt GC; Source: Author

Figure 4.7 shows the promotion levels of GC in current practices among the construction industry. The x-axis represents the promotion level of GC, ranging from 0 to 10, where 0 denotes no promotion and 10 denotes the highest level of promotion. The y-axis represents the frequency of the given scores by participants regarding their opinion on the promotion level of GC.

The graph shows that the majority of individuals consider a moderate level of promotion for GC, with promotion levels ranging from 2 to 5. The highest frequency of promotion level was found to be 3 and 4, with 21 and 17 responses, respectively.

Overall, the graph suggests that while there is a moderate level of promotion for GC in current practices, there is still room for improvement in terms of increasing the level of promotion.

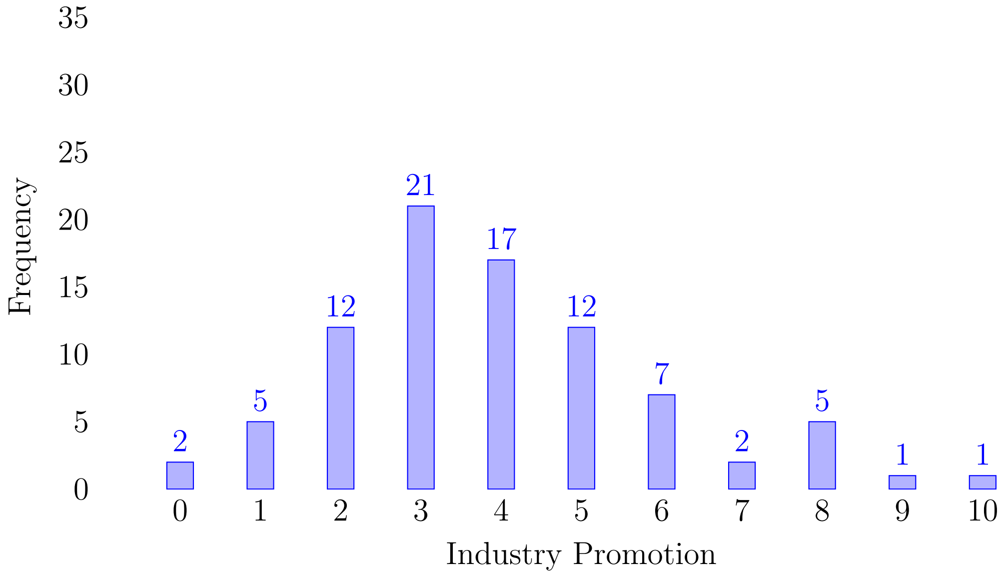

Figure 4.7: Promotion Levels of GC in current practices; Source: Author

4.1.5 Prior Practical Experience with Green Concrete or other Innovations and Future Interest

"Did you have any opportunity to work with Green Concrete or other new innovative material?"
"Would you like to work on a project that involves Green Concrete or other innovative material?"

To create a deeper understanding of the sample size, the survey included questions about prior experiences with GC or other innovative materials and also about future interest. 21 respondents out of 85 had previously come across a variation of green concrete in their work, whereas the rest 64 did not have any practical experience, see Figure 4.8.

The pie-chart in Figure 4.9 displays a large interest of individuals that would like to work with GC or other innovative materials, with 67 positive responses and 17 answers with "Maybe".

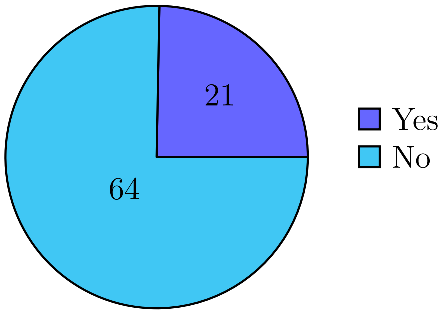

Figure 4.8: Prior experience with GC/other material: Source: Author

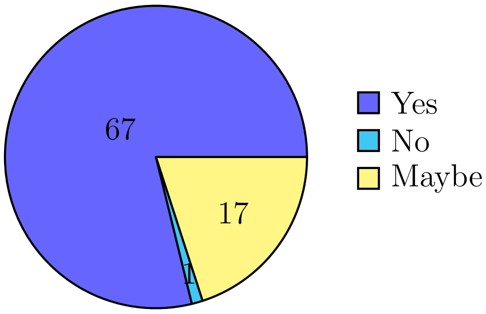

Figure 4.9: Future Interest in GC/other material: Source: Author

4.1.6 Green Concrete: Challenges & Concerns

"What were the main challenges when working with Green Concrete or other Innovation?
"What is your main concern regarding Green Concrete?"

Based on the list of words from Appendix C, Figure 4.10 summarises the results. It appears that the most frequently mentioned challenges when working with green concrete include regulations, rules, standards, and norms, which were mentioned a total of 34 times. The next most common challenge was cost, which was mentioned 11 times, followed by properties and time, each mentioned 9 times. Other commonly mentioned challenges include client-related issues, such as approvals and investments, as well as concerns about knowledge and experience.

Figure 4.10: Green Concrete Main Challenges; Source: Author

In Figure 4.11, which is based on the list provided in Appendix C, it can be seen that the most common challenges associated with green concrete include the lack of experience and knowledge, the long-term durability and behaviour, the availability, the reliability, the standards and regulations, and the supply chain. It is interesting to note that the greenness of green concrete is also a concern for some participants, indicating a need for better communication and education on the topic. The results also suggest that there is a need for more validation, proof, and promotion of green concrete to increase its acceptance and applicability in the industry.

Figure 4.11: Green Concrete Main Concerns; Source: Author

4.1.7 Prioritisation of the Sustainability Dimensions

"How would you prioritise the 3 given aspects of sustainability when it comes to Green Concrete?"

The results of this question highlight the prioritisation of the sustainability dimensions when it comes to choosing GC. As presented in the graph from Figure 4.12, the Environment dimension, with 67 responses, is the first considered factor when selecting GC as a construction material, followed by Society, with 62, and lastly, Economy with 63 votes. The figure helps to understand the perceptions and priorities of stakeholders regarding possible influencing factors in the context of green concrete.

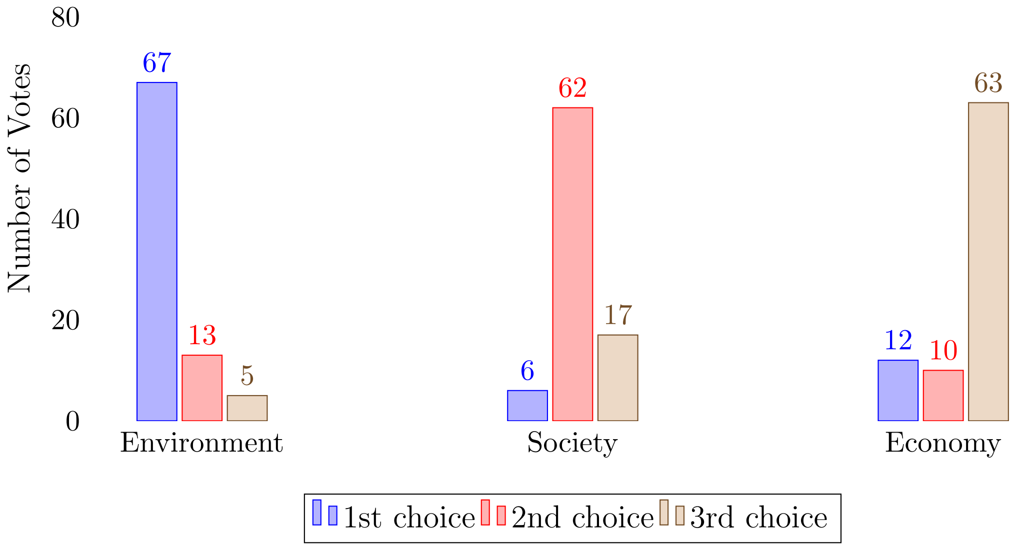

Figure 4.12: Prioritisation of sustainability dimensions for GC; Source: Author

4.1.8 Impact Rating of the 10 most common barriers to Innovation

"According to literature, these are 10 of the most common barriers to innovation. On a scale from 1 to 5, how would you grade them by impact?"

Based on the obtained data, the mean and standard deviation of the ratings for each barrier to innovation are calculated in Table 4.2. This will give an idea of the average impact of each barrier and how much the ratings vary across participants. The mode is also calculated, which helps to see which rating was most commonly assigned to each barrier.

The mean is the average rating given to each barrier by the participants on a scale of 1 to 5, where 1 indicates the least impact and 5 indicates the greatest impact. A higher mean score indicates that the barrier has a greater impact on innovation. Based on the mean values, “Short-term thinking” was rated as the most significant barrier to innovation, followed by “Lack of focus” and “Lots of ideas, no market delivery”. “No time” was rated as the least significant barrier to innovation.

The standard deviation is a measure of the spread or variability of the ratings given by the participants. A higher standard deviation indicates that the ratings are more spread out, indicating greater variability in the participants' perceptions. Based on the standard deviation values, "Fear" and "Short-term thinking" have the highest variability in their ratings, while "No time" has the lowest variability.

The mode is the rating that appears most frequently for each barrier. It indicates the most common rating given by the participants. Based on the mode values, "Short-term thinking", "Lack of resource/capacity", "Lack of focus", "Lots of ideas, no market delivery", and "No clear process" were rated most frequently as having the greatest impact on innovation, while "Lack of leadership" and "No time" were rated most frequently as having a lesser impact on innovation.

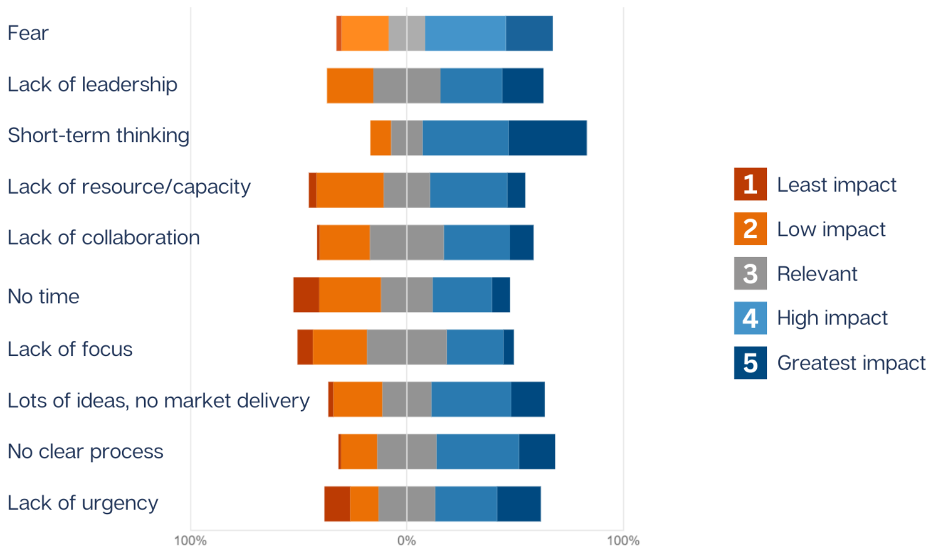

Figure 4.13: Impact assessment of 10 most common barriers to innovation; Source: Author

Barrier	Mean	Standard Deviation	Mode
Fear	3.42	1.27	4
Lack of leadership	3.16	1.26	2
Short-term thinking	3.94	1.13	4
Lack of resource/capacity	3.08	1.24	4
Lack of collaboration	3.31	1.17	3
No time	2.66	1.11	3
Lack of focus	3.33	1.17	4
Lots of ideas, no market delivery	3.37	1.22	4
No clear process	3.28	1.10	4
Lack of urgency	3.13	1.14	3

Table 4.2: Descriptive statistics of barriers to innovation

4.1.9 Likelihood of recommending Green Concrete

"How likely are you to recommend Green Concrete as a reliable construction solution?"

The Figure 4.14 shows the frequency distribution of responses to a question about the likelihood of recommending GC on a scale from 0 to 10. The most common response was 7, followed by 5 and 8, with a total of 56 responses between them. The distribution is skewed to the right, indicating a generally positive attitude towards recommending GC. The mean score is 6.24, and the median score is 7, indicating that the majority of responses were towards the higher end of the scale. The standard deviation is 2.62, indicating a relatively high level of variability in responses. For this study, a high variability is expected as the research is aimed to identify factors that influence the implementation of GC in practical applications.

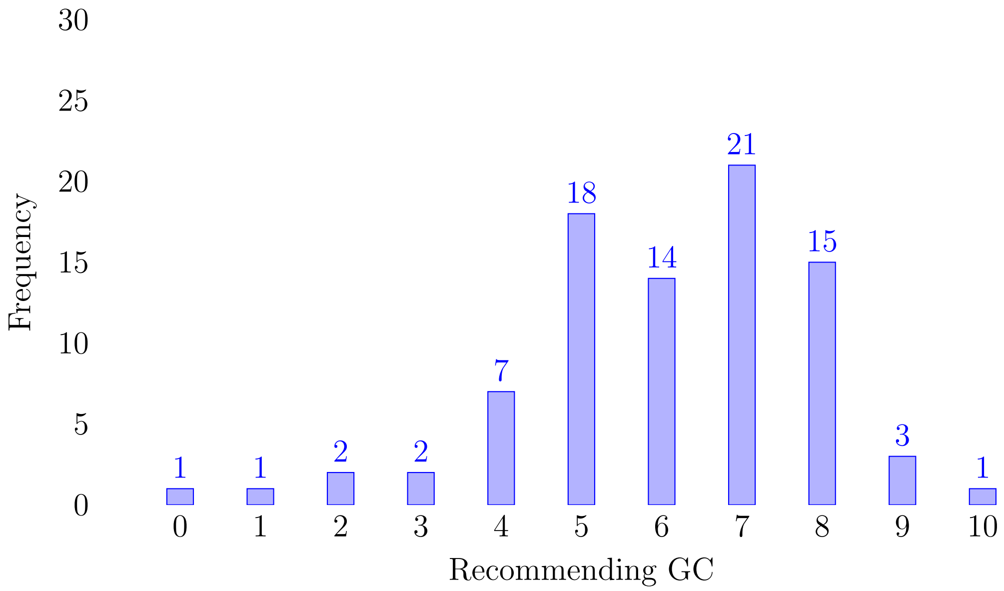

Figure 4.14: Likelihood of recommending GC; Source: Author

4.1.10 Interest in further discussions

"Would you be willing to possibly discuss further this topic in an interview?"

As one of the last question of the survey, this was intended to help further with the next stage of this research project, the semi-structured interviews. Almost half of the respondents showed interest in discussing further the topic of this thesis, see Figure 4.15.
Since 44 individuals responded "Yes" to the question, a selection process was performed. The main criterion to further interview the participants was their prior experiences with GC. Therefore, as presented in Figure 4.8 only 21 individuals made it into the second round of selection.

Because the survey was conducted with only Witteveen+Bos employees, the second stage of selection consisted in contacting the people with the most experience in terms of GC, but also based on their availability. The scope of the interviews included external stakeholders, that is why from 19 spots available, 5 had to be filled in by people from outside the company. In Chapter 5, Table 3.1 an extensive explanation of the interviewed individuals is provided. Since all the survey questions relate to the GC and its implementation in practical applications, a scaling process is required to observe which of the findings resulted from the survey are more relevant, and how those findings relate to one another. For this, in the following Sub-section, a Factor Analysis is performed, highlighting 7 important variables to consider when choosing GC as a construction material.

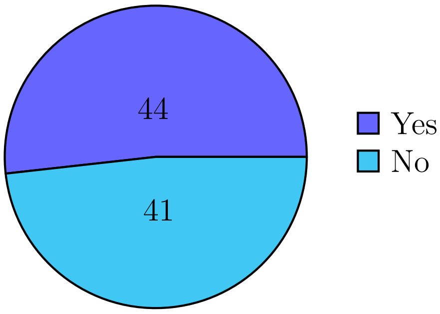

Figure 4.15: Responses to willingness to discuss further in an interview; Source: Author

4.2 Factor Analysis

In order to perform the factor analysis, only 10 of the survey questions were considered and clustered in sets of variables that describe the influence factors in the implementation of GC in construction projects. From Table 4.3, starting from "Familiarity with GC" until "Recommending GC" describe a personal belief, trait, experience, etc. The industry openness, acceptance, and promotion enlarge the horizons to a generalised view of what is happening in practice. The last 10 variables engage in finding a possible issue or multiple issues in the implementation process. In total 19 variables were considered for this factor analysis.

From the Table 4.3, it is clear that the respondents, on average, have a high level of familiarity with GC and a high level of importance and acceptance of GC in the industry. However, there is some variability in responses, as indicated by the relatively large standard deviation values for these variables.

Short-term thinking and a lack of resources/capacity are recognised as the most major impediments to adopting GC, but the respondents also mention relatively low levels of anxiety and a lack of leadership. There is some potential for the sector to embrace GC, but there is still space for development, as indicated by the moderate levels of the variables linked to industry promotion, openness, and acceptance.

Variables	Mean	Std. Deviation	Analysis N
Familiarity with GC	4.68	2.503	85
Relevance of GC	1.39	.788	85
Importance of GC	7.89	1.589	85
Prior experience with GC/other material	1.75	.434	85
Interest in GC	1.41	.806	85
Recommending GC	6.08	1.827	85
Industry Openness	5.08	2.089	85
Industry Acceptance	6.46	1.524	85
Industry Promotion	3.94	2.026	85
Fear	3.53	1.119	85
Lack Of Leadership	3.46	1.030	85
Short-term Thinking	4.02	.951	85
Lack of Resource/Capacity	3.14	1.060	85
Lack of Collaboration	3.28	.983	85
No Time	2.89	1.185	85
Lack of Focus	2.95	.999	85
Lots of Ideas, No Market Delivery	3.40	1.071	85
No Clear Process	3.52	.995	85
Lack of Urgency	3.31	1.273	85

Table 4.3: Descriptive Statistics of Factor Analysis Variables

The Correlation Matrix

The correlation matrix shows the correlation coefficients between all pairs of variables in the survey. The correlation coefficient ranges from -1 to 1, where -1 indicates a perfect negative correlation, 0 indicates no correlation, and 1 indicates a perfect positive correlation. In general, a correlation coefficient of 0.3 or higher indicates a moderate correlation, while a coefficient of 0.7 or higher indicates a strong correlation (Janse et al., 2021). (The correlation matrix can be found in Appendix D divided across Figure D.1, Figure D.2, and Figure D.3 due to its large size.)

Looking at the correlation matrix, in Figure D.1, Figure D.2, and Figure D.3, it can be seen that the variables "Familiarity with GC," "Interest in GC," and "Recommending GC" are moderately to strongly positively correlated with each other, which indicates that individuals who are familiar with green concrete are more likely to be interested in it and recommend it to others. We can also see that "Industry Openness" and "Industry Acceptance" are moderately positively correlated with each other, which suggests that companies that are open to adopting new technologies and ideas are more likely to accept and implement green concrete.

On the other hand, some variables are negatively correlated with each other. For example, "Fear" is negatively correlated with "Industry Openness" and "Industry Acceptance," which suggests that fear may be a barrier to companies adopting green concrete. Similarly, "Short-term Thinking" is negatively correlated with "Importance of GC," which suggests that companies that prioritise short-term goals may not see the importance of investing in green concrete.

It is worth noting that the determinant of the correlation matrix is 0.008, which is less than 0.05, indicating that the variables are not perfectly correlated and that a factor analysis can be performed.

KMO & Bartlett's Test of Sphericity

The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy and Bartlett's Test of Sphericity are used to evaluate the appropriateness of performing factor analysis on the given data. The KMO measure ranges from 0 to 1, with values closer to 1 indicating that the sample size is adequate for factor analysis (Janse et al., 2021). A value above 0.5 is generally considered acceptable, and in this case, the KMO value of 0.658 suggests that the data is suitable for factor analysis, see Table 4.4.

Bartlett's Test of Sphericity is a statistical test that checks if the correlation matrix is significantly different from an identity matrix. If the test is significant (i.e., p-value < 0.05), then it is appropriate to perform factor analysis on the data. In this case, the test yielded a significant p-value of 0.000, indicating that the correlations between the variables are sufficiently large for factor analysis.

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0,658
Bartlett's Test of Sphericity	Approx. Chi-Square	368,572
	df	171
	Sig.	0,000

Table 4.4: Factor Analysis - KMO and Bartlett's Test

Communalities

The communalities Table 4.5 shows the amount of variance in each variable that can be explained by the extracted factors (Stephanie, 2020). The initial communalities column shows the proportion of variance in each variable before the extraction of factors, while the extraction column shows the proportion of variance that can be explained by the extracted factors. In this analysis, principal component analysis was used to extract the factors. The communalities table can be used to determine which variables have high or low communalities and to decide which variables to include in the final factor solution. Variables with low communalities may not contribute much to the factor analysis and may be dropped from the final analysis.

Communalities		
	Initial	**Extraction**
Familiarity with GC	1,000	0,752
Relevance of GC	1,000	0,675
Importance of GC	1,000	0,637
Prior experience with GC/other material	1,000	0,782
Interest in GC	1,000	0,556
Recommending GC	1,000	0,664
Industry Openness	1,000	0,615
Industry Acceptance	1,000	0,484
Industry Promotion	1,000	0,655
Fear	1,000	0,620
Lack Of Leadership	1,000	0,682
Short-term Thinking	1,000	0,698
Lack of Resource/Capacity	1,000	0,531
Lack of Collaboration	1,000	0,558
No Time	1,000	0,724
Lack of Focus	1,000	0,699
Lots of Ideas, No Market Delivery	1,000	0,577
No Clear Process	1,000	0,736
Lack of Urgency	1,000	0,673
Extraction Method: Principal Component Analysis.		

Table 4.5: Factor Analysis - Communalities

Total Variance Explained

The "Total Variance Explained" Table 4.6 provides information on the amount of variance explained by each extracted component or factor, both before and after rotation.

The "Initial Eigenvalues" column shows the eigenvalue of each component before extraction, which represents the amount of variance in the original variables that can be accounted for by each component. The eigenvalues are sorted in descending order, and the number of components to be retained can be determined by looking at the point at which the eigenvalues start to level off.

The "Extraction Sums of Squared Loadings" column shows the total amount of variance accounted for by each component after extraction, which is calculated by summing the squared factor loadings for each variable onto that component. This column shows the percent of variance explained by each component, as well as the cumulative percent of variance explained by all the components up to that point.

The "Rotation Sums of Squared Loadings" column shows the variance accounted for by each component after rotation, which is also calculated by summing the squared factor loadings for each variable onto that component. This column also shows the percent of variance explained by each component, as well as the cumulative percent of variance explained by all the components up to that point.

The goal of factor analysis is to identify the underlying factors that explain the correlations among a set of observed variables. In this case, it seems that the extracted factors account for a substantial proportion of the variance in the original set of variables. The number of factors to retain is typically determined by looking at the eigenvalues, and a scree plot can be used to visualise the point at which the eigenvalues start to level off. The results of the factor analysis can be used to interpret the factors and to identify the variables that are most strongly associated with each factor (Young, 2021).

Total Variance Explained						
Component	**Initial Eigenvalues**		**Extraction Sums of Squared Loadings**		**Rotation Sums of Squared Loadings**	
	Total	% of Variance	Total	% of Variance	Total	% of Variance
1	3,731	19,635	3,731	19,635	3,158	16,623
2	2,004	10,550	2,004	10,550	1,861	9,793
3	1,829	9,627	1,829	9,627	1,581	8,323
4	1,463	7,701	1,463	7,701	1,502	7,903
5	1,174	6,180	1,174	6,180	1,461	7,689
6	1,107	5,826	1,107	5,826	1,429	7,519
7	1,010	5,314	1,010	5,314	1,327	6,982
8	0,976	5,138				
9	0,802	4,223				
10	0,732	3,853				
11	0,689	3,628				
12	0,680	3,578				
13	0,611	3,215				
14	0,513	2,699				
15	0,431	2,271				
16	0,388	2,041				
17	0,349	1,839				
18	0,288	1,516				
19	0,222	1,167				

Table 4.6: Factor Analysis - Total Variance Explained

Scree Plot

A scree plot is a graphical representation of the eigenvalues associated with the factors extracted from a factor analysis. It is used to determine the number of factors to retain. The plot displays the eigenvalues of each factor extracted, with the eigenvalues listed in decreasing order on the y-axis and the number of factors on the x-axis. The plot shows a "scree" pattern where the eigenvalues decrease steeply for the first few factors and then level off for the remaining factors. The point where the plot levels off is known as the "elbow" of the scree plot (Lewith et al., 2010).

The elbow of the scree plot is used as an indicator for the number of factors to retain. Factors before the elbow are considered significant and should be retained, while those after the elbow are less significant and can be discarded. The exact location of the elbow can be subjective and dependent on the specific data-set and research question.

In summary, the scree plot is a useful tool for determining the number of factors to retain in a factor analysis, as it visually displays the eigenvalues associated with each factor and the point at which the eigenvalues level off.

In this analysis, the scree plot, Figure 4.16 shows a steep drop in eigenvalues between the first and second components, followed by a more gradual decline in subsequent components. This suggests that a 2-component solution may be appropriate for this data, as the first two components account for the majority of the variance (30.2%). A 3-component solution may also be considered, as the first three components explain 39.8% of the variance. However, beyond the third component, there is no clear point where the curve levels off, indicating that additional components may not add much explanatory power. Overall, the scree plot suggests that a 2- or 3-component solution may be appropriate for this data.

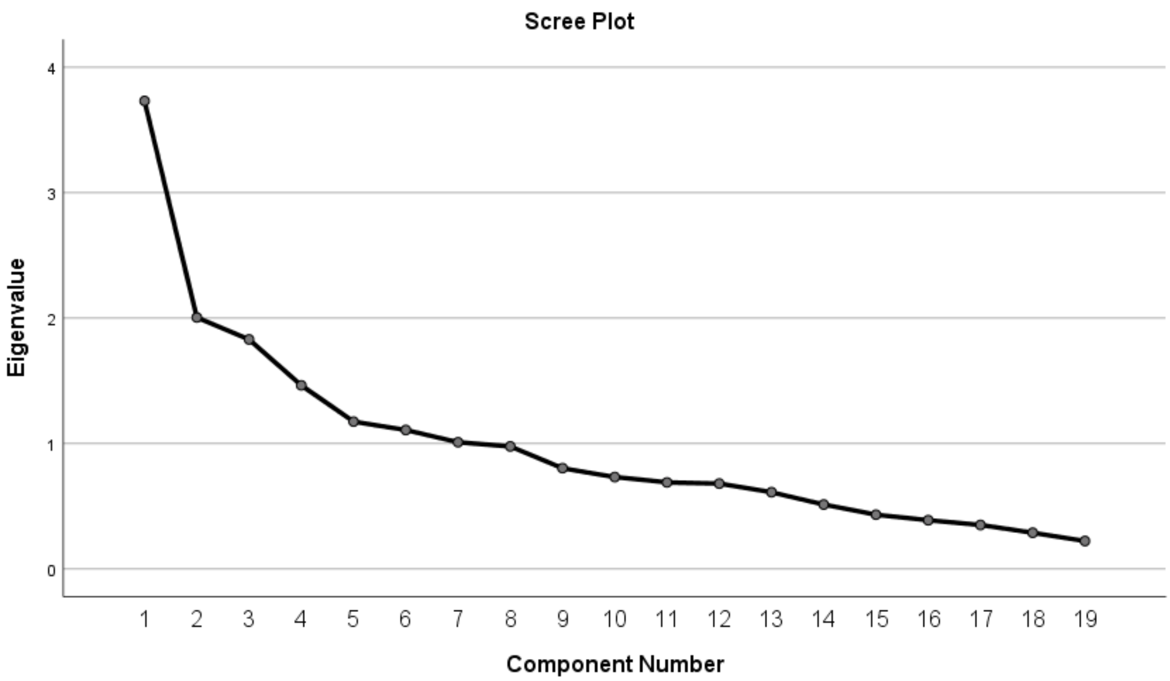

Figure 4.16: Scree plot of eigenvalues; Source: SPSS

Component Matrix

The component matrix, Table 4.7 shows the correlation coefficients between the original variables and each of the seven principal components identified through the factor analysis. Each variable has a loading (correlation) on each component. The higher the loading, the more that variable contributes to that component (Bruin, 2011).

For example, the variable "Familiarity with GC" has a high loading on the first component, suggesting that it is strongly associated with this component. The variables "Recommending GC" and "Importance of GC" have high loadings on the first and third components, respectively.

The interpretation of the components will depend on the variables that load on them. Based on this component matrix, the first component seems to be related to variables such as Familiarity with GC, Recommending GC, and Importance of GC, which may suggest a general attitude towards the topic of green concrete. The second component seems to be more related to variables such as Lack of Focus, No Time, and Lack of Resource/Capacity, which may suggest barriers or challenges in implementing green concrete practices.

Component Matrix[a]							
	Component						
	1	2	3	4	5	6	7
Familiarity with GC	0,808	-0,087	-0,068	0,187	-0,067	-0,173	0,131
Recommending GC	0,746	-0,240	-0,095	0,030	0,060	-0,133	-0,135
Relevance of GC	-0,666	0,042	-0,105	0,285	-0,014	0,047	0,368
Interest in GC	-0,602	0,382	-0,001	-0,083	-0,150	0,064	0,123
Prior experience with GC/other material	-0,590	0,126	0,060	-0,230	0,415	0,382	-0,208
Importance of GC	0,563	-0,148	0,394	-0,264	-0,196	-0,028	-0,184
Industry Acceptance	0,494	-0,001	-0,150	-0,328	0,150	0,294	-0,026
Industry Openness	0,461	0,222	-0,309	-0,143	-0,079	0,460	0,138
No Clear Process	0,241	0,554	-0,115	0,252	0,293	0,063	-0,452
Lack of Focus	0,367	0,544	0,384	0,218	-0,108	0,176	0,179
Lack of Resource/Capacity	-0,058	0,537	0,098	-0,266	-0,023	-0,398	0,011
No Time	0,278	0,510	-0,021	-0,352	0,021	-0,347	0,376
Lack of Urgency	0,004	0,183	0,684	0,258	-0,189	0,114	-0,236
Short-term Thinking	0,051	-0,161	0,627	-0,161	0,244	0,147	0,411
Industry Promotion	0,427	0,345	-0,471	0,018	0,066	0,298	0,197
Fear	-0,021	-0,042	-0,295	0,509	0,413	-0,309	0,072
Lots of Ideas, No Market Delivery	0,045	0,389	-0,002	0,506	-0,396	0,099	-0,038
Lack Of Leadership	0,347	-0,237	0,331	0,413	0,351	0,175	0,265
Lack of Collaboration	0,107	0,409	0,277	-0,067	0,505	-0,188	-0,091
Extraction Method: Principal Component Analysis.							
a. 7 components extracted.							

Table 4.7: Factor Analysis - Component Matrix

Rotated Component Matrix

The rotated component matrix in Table 4.8 shows the correlations between the original variables and the new, rotated components. In this case, the components have been rotated using a varimax rotation with Kaiser normalisation. The table shows the factor loadings (correlations) of each variable with each of the seven rotated components. The higher the absolute value of a loading, the more that variable is associated with that component (Bruin, 2011).

Interpreting the rotated component matrix requires looking at the pattern of loadings across components for each variable. Variables with high loadings on a particular component are more strongly associated with that component. In this case, we can see that the first component is characterised by high loadings on "Recommending GC," "Familiarity with GC," and "Prior experience with GC/other material," while the second component is characterised by high loadings on "Industry Promotion" and "Industry Openness." By examining the pattern of loadings across components, we can gain insight into the underlying factors that are driving the relationships among the variables.

Component Transformation Matrix

The Component Transformation Matrix shows the relationship between the original variables and the rotated components. It is used to calculate the scores for each component for each observation in the data-set.

In this case, there are 7 components and the matrix shows the loadings of each variable on each component after rotation, see Table 4.9. The numbers in the matrix represent the correlation between the variables and the components. The higher the absolute value of the correlation, the stronger the relationship between the variable and the component. The matrix is used in conjunction with the rotated component matrix to interpret the meaning of each component.

The factor analysis identified seven factors with eigenvalues greater than 1, which accounted for 64.832% of the total variance. The scree plot and parallel analysis also supported the extraction of seven factors. The rotated component matrix shows the factor loadings for each variable after rotation, and the interpretation of the factors was based on these loadings and the content of the variables. The communalities table shows the amount of variance in each variable accounted for by the extracted factors. Overall, the factor analysis suggests that there are seven underlying factors that explain the common variance among the variables related to the adoption of green concrete. These factors are: Industry Promotion and Support, Positive Attitudes and Beliefs towards Green Concrete, Resource and Capacity Constraints, Market-related Obstacles, Lack of Leadership and Vision, Collaboration and Communication Issues, Time-related Constraints.

Rotated Component Matrix[a]							
	Component						
	1	2	3	4	5	6	7
Recommending GC	0,785	0,181	-0,075	-0,056	0,000	0,016	0,074
Familiarity with GC	0,782	0,253	0,176	0,103	0,096	0,136	-0,082
Prior experience with GC/other material	-0,689	-0,006	-0,300	-0,197	0,073	-0,129	0,396
Interest in GC	-0,684	-0,071	0,137	0,208	-0,127	-0,040	-0,067
Relevance of GC	-0,637	-0,139	0,102	-0,060	0,059	0,388	-0,286
Importance of GC	0,568	-0,042	0,036	0,058	0,147	-0,533	0,034
Industry Promotion	0,112	0,760	0,116	0,106	-0,086	0,169	0,064
Industry Openness	0,135	0,753	0,097	-0,001	-0,024	-0,142	-0,015
Industry Acceptance	0,291	0,524	-0,218	-0,013	0,072	-0,230	0,139
Lots of Ideas, No Market Delivery	-0,046	0,068	0,724	-0,029	-0,187	0,097	-0,015
Lack of Focus	0,087	0,229	0,639	0,267	0,325	-0,131	0,191
Lack of Urgency	-0,007	-0,351	0,552	-0,093	0,246	-0,346	0,238
No Time	0,096	0,236	-0,001	0,809	0,063	-0,002	-0,001
Lack of Resource/Capacity	-0,115	-0,110	0,064	0,663	-0,139	-0,084	0,189
Short-term Thinking	-0,031	-0,102	-0,090	0,075	0,791	-0,210	-0,058
Lack Of Leadership	0,303	0,043	0,144	-0,260	0,658	0,246	0,080
Fear	0,104	-0,090	-0,028	-0,053	-0,016	0,757	0,155
No Clear Process	0,081	0,217	0,286	0,040	-0,221	0,143	0,727
Lack of Collaboration	0,008	-0,065	-0,030	0,367	0,245	0,064	0,595
Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization.[a]							
a. Rotation converged in 9 iterations.							

Table 4.8: Factor Analysis - Rotated Component Matrix

Component Transformation Matrix							
Component	**1**	**2**	**3**	**4**	**5**	**6**	**7**
1	0,863	0,429	0,133	0,104	0,140	-0,103	0,111
2	-0,326	0,293	0,484	0,596	-0,150	-0,009	0,443
3	0,023	-0,514	0,281	0,071	0,644	-0,458	0,164
4	0,092	-0,169	0,637	-0,399	0,059	0,626	0,053
5	-0,056	0,074	-0,493	-0,021	0,420	0,423	0,627
6	-0,334	0,597	0,143	-0,583	0,237	-0,335	0,059
7	-0,157	0,275	0,015	0,361	0,554	0,311	-0,605
Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalisation.							

Table 4.9: Factor Analysis - Component Transformation Matrix

4.3 Relative Importance Index

The Relative Importance Index (RII) is a method to mark the relative importance of a specific set of variables. It is a common method used in social sciences or marketing to highlight opinions, attitudes, or behaviour of respondents related to the given variables. For this study, the set of variables picked to undergo a RII analysis is the ten most common barriers to innovation described in Section 4.1.8. The respondents were asked to rate the impact of the given barriers to innovation from 1 to 5, 1 being the least impact and 5 being the most impactful. In Table 4.10 the total score for each challenge is given by summing up the scores for each level of impact.

		Impact				
ID	**Challenges**	**5**	**4**	**3**	**2**	**1**
1	Fear	18	31	16	18	2
2	Lack Of Leadership	16	25	26	18	0
3	Short-term Thinking	31	33	13	8	0
4	Lack of Resource/Capacity	7	30	19	26	3
5	Lack of Collaboration	10	25	30	19	1
6	No Time	7	23	20	24	11
7	Lack of Focus	4	22	31	22	6
8	Lots of Ideas, No Market Delivery	13	31	20	19	2
9	No Clear Process	14	32	24	14	1
10	Lack of Urgency	17	24	22	12	10

Table 4.10: Total score for each challenge

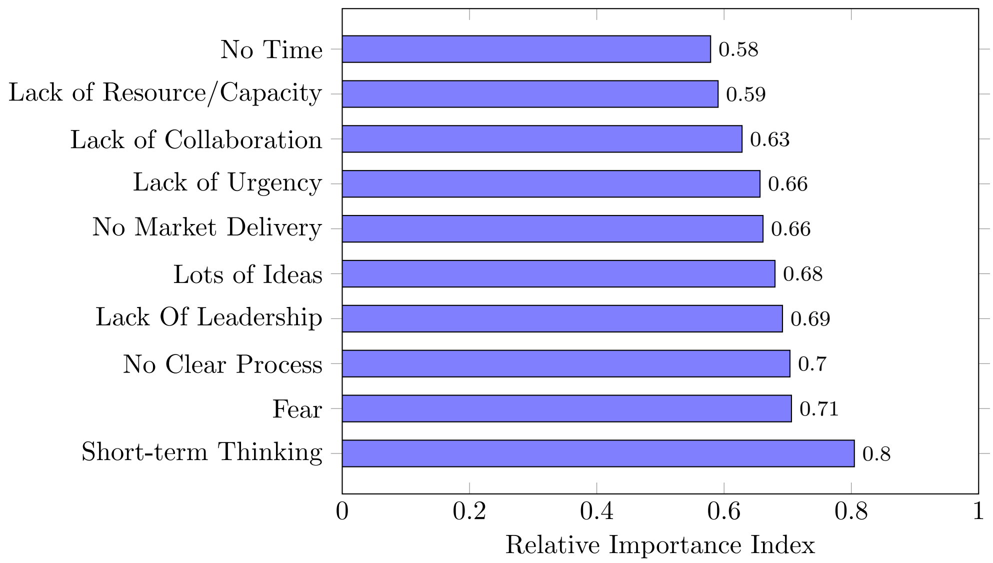

Figure 4.17: Relative Importance Index of the 10 most common barriers to innovation; Source: Author

In Table 4.11 the calculation for obtaining the RII is presented, whereas the results of the RII are illustrated in Figure 4.17.

The numbers in columns "5" through "1", in Table 4.11, represent the frequency of each response, where 5 is the highest impact and 1 is the lowest. The "Total" column is the sum of the frequencies. The "N" column is the total number of respondents. The "A*N" column is the product of the frequency and the number of respondents. The "RII" column is the Relative Importance Index, calculated using the formula

$$RII = \frac{\sum W}{A \times N} \text{ where,}$$

W is the weighting assigned on Likert's scale by each respondent, A is the highest weight, and N is the total number of respondents. The "Rank" column is the rank of the barrier based on its RII, with 1 being the highest. The results of RII confirm the findings in Section 4.1.8, but explain in-depth how the listed factors weight in terms of impact in the process of implementing GC.

In conclusion, "short-term thinking" impacts the most the process of implementing GC in construction projects, at least from the point of view of Witteveen+Bos employees. Looking at the rest of the barriers in Figure 4.17, the differences between the coefficients is not very high, thus all of them interfere with the process in a certain amount.

ID		5	4	3	2	1	Total	N	A*N	RII	Rank
1	Fear	90	124	48	36	2	300	85	425	0.70	2
2	Lack Of Leadership	80	100	78	36	0	294	85	425	0.69	4
3	Short-term Thinking	155	132	39	16	0	342	85	425	0.80	1
4	Lack of Resource/Capacity	35	120	57	52	3	267	85	425	0.62	8
5	Lack of Collaboration	50	100	90	38	1	279	85	425	0.65	7
6	No Time	35	92	60	48	11	246	85	425	0.57	10
7	Lack of Focus	20	88	93	44	6	251	85	425	0.59	9
8	Lots of Ideas, No Market Delivery	65	124	60	38	2	289	85	425	0.68	5
9	No Clear Process	70	128	72	28	1	299	85	425	0.70	3
10	Lack of Urgency	85	96	66	24	10	281	85	425	0.66	6

Table 4.11: Relative Importance Index calculation

Chapter 5

Semi-structured Interviews Results

This chapter presents the results of the interviews conducted with specialists from the construction sector regarding the implementation of green concrete solutions in construction projects. 19 specialists with different backgrounds, expertise, and experiences took part in the interviewing sessions, expressing their views and opinions on the matter at hand.

The semi-structured interviews together with the literature review were designed to answer the third and fourth sub-research questions of this study, which are:

What are the key factors that influence the decision to adopt green concrete solutions in construction projects, and how can these be leveraged to promote the widespread implementation of these solutions?

What are the possibilities in terms of practices and strategies for integrating green concrete solutions into the design and construction process, ensuring that they are seamlessly integrated into the project and meet the required performance standards?

As described in Chapter 3, the Grounded Theory Method is used to analyse the data retrieved from the interviews. Since it is an iterative process, multiple layers of revision were performed, including open coding, axial coding and selective coding to allow for more in-depth understanding and observations in terms of patterns and themes.

5.1 Coding Frame

Based on the Methodology, as explained in Section 3.2, the data resulted from the interviews stage went through multiple review stages. After the transcription of the 19 interviews, a grammatical correction was performed to clean up the irrelevant text. To familiarise with the content of the interviews, an initial reading was done together with the quotation step. The quotation step represents highlighting the ideas that seem to be relevant or stand out from the entire content of the transcript and are the foundation of coding for the qualitative analysis.

From the 19 interviews conducted for the research, 542 quotations resulted from the initial study of the transcripts. Based on these highlights, 37 open codes were generated that explain what the quotations refer to. To narrow down the findings of the interviews, out of 37 open codes, 5 axial codes were created to describe the overall ideas presented by the open codes. The axial codes concentrate the information into concepts that would finally lead to the finite aggregate category, which is important for answering the sub-research questions. The coding framework of analysis is represented in Figure 5.1.

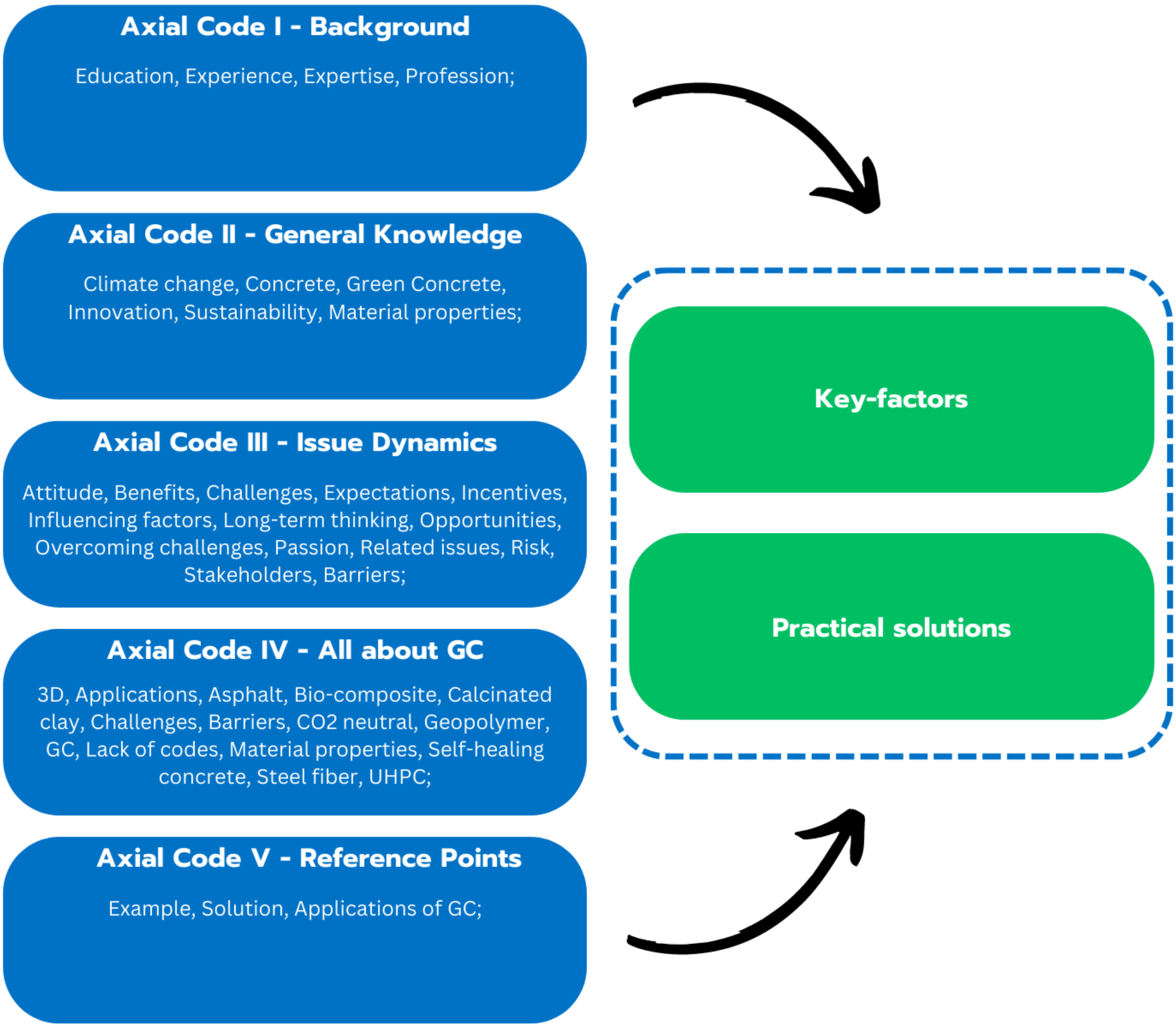

Figure 5.1: Interviews Analysis - Coding Framework; Source: Author

5.2 Interviews Findings

In this Subsection, the findings of the interviews will be presented following the order of the interview questions listed in Section 3.2.3.

5.2.1 Professional Input

Each of the interviewed individuals have a distinct background with different professions, years of experience and professional expertise. The fact that each individual has a distinct background with different professions, years of experience, and professional expertise means that they are likely to have different perspectives and insights on the topic you are researching. The diversity helps contour a better image of the actual status of GC in the construction sector, and it can increase generalisability and validity of the research.

"I am an engineer in the province of Friesland in civil constructions, I estimate the cost of constructions especially with concrete and steel. I worked for the municipality for the past 10 years and before that in several other companies." - EXT_4

"I am a civil engineer, I work at TU Delft and Rijkwaterstaat about procurement strategies and contracting strategies for exceptional tasks and changes that we want in the construction sector. Basically, I advise, I formulate strategies, but I am not hands-on projects. I worked for Rijkwaterstaat for 27 years." - EXT_2

"I started my career in 2008 after I graduated from TU Delft. I started in a different company where I did inspections of concrete structures. We did lab testing on concrete structures, materials and different types of binders. I did a lot of monitoring and modelling of concrete. Here we continue this work. We work on making a sustainable concrete solution." - WB_8

The majority of the interviewed people have backgrounds in civil engineering, but they specialise in various fields or have specific areas of interest, such as project management, concrete technology, water management, sustainability, and innovation.

Some responders are active in many facets of research and development connected to concrete technology and have expertise with 3D concrete printing, a new technology in the construction business. Others have expertise in sustainable practises and circular solutions, which demonstrates the growing significance of environmental issues and sustainable practises in the construction sector.

Others have expertise in more broad areas like building technology, construction management, and procurement techniques. Other respondents have experience in niche areas of construction including bridges, tunnels, and road infrastructure.

Overall, the data collected on each person's background shows how diverse and complicated the construction sector is, as well as the variety of skills and experience needed to succeed in this area.

5.2.2 General Knowledge

To build a strong basis for the interview questions that refer strictly to the issue studied by this research, a personal point of view check was performed on each individual. After the introductory part of the conversation, the participants were asked to define sustainability, innovation, green concrete and stakeholder power in terms of implementing innovations. By doing this, it was ensured that the participants have a fundamental comprehension of the important ideas that were covered throughout the interview. Additionally, as it was found in the Literature study, often the perception of things in the real-world differs from the academic environment, therefore this step was important to observe if the gap is prominent.

Sustainability

Regarding sustainability, the responses indicate that people's perceptions of sustainability are multidimensional and entail balancing different elements, including social, economic, and environmental considerations. Finding solutions that reduce impact, promote circularity and bio-based materials, take into account the full life cycle, and strike a balance between the requirements of the present and future generations are all part of sustainability. In addition, durability and service life are stressed, along with the significance of protecting the environment and natural resources. Many think that circularity and sustainability should be considered throughout a structure's life cycle. Furthermore, it is acknowledged that sustainability is a complicated problem that necessitates systemic thinking and a comprehensive sustainability framework. Ultimately, some individuals see that there has to be a rethinking of conventional building practises and that there is a lack of action on sustainability.

"I do believe that we need to put more effort in really understanding their overlap (sustainability dimensions), because in the end you cannot simplify the problem by isolating subjects to make it tenable just for a human brain. - EXT_1

"For me, it is very much related to service life. It is our effort to maintain as much as we can or build structures that are able to resist a long time and if you then divine the cost of the structure with the years of service, you get a good performance. All the solutions that can help achieve that bring sustainability in construction. If a solution is good for the environment, but has a very low service life, like 10 years, then for me that is not sustainable. We need to think about the long-term effect." - EXT_5

"Future-proof and climate-neutral planning does not imply that it is not impactful on climate change; on the contrary, it should aim to reverse it if possible." - WB_16

Innovation

According to the responses, individuals define innovation as the process of developing new methods, materials, or technology in the construction sector. Innovation is viewed as a continual process requiring zeal, aspiration, investigation, and the creation of pertinent facts. The necessity of sustainable development and the movement towards climate neutrality fuel the demand for innovation. Due to high investment costs, associated risks, and industrial conservatism, innovations face difficulties in implementation. To reduce risks and have a strong business case, it is crucial to implement innovation in the appropriate setting. Moreover, there are other aspects of innovation, such as technological, process, and social innovation. Suppliers are seen to innovate a lot, particularly in the area of circularity, and policy is considered as a crucial driver of innovation.

"If we want to innovate the construction industry, automation is important, but we should also innovate materials because there haven't been many differences made in them." - WB_14

"As an innovator, I understand the risks that come with it, but others often shy away from it. Innovation requires collaboration, not just from clients, suppliers, and universities, but also from engineering companies. The key is to bridge the gap between theory and practice, and to simplify complex ideas. It's important to dare to take risks and not be afraid of the effort it takes to innovate." - EXT_3

"Innovation is a process of creating something new and finding a market for it. At the end, it must be applied on a large scale. The process can be short if you have a good idea and create all the necessary elements, such as a proof of concept, to bring the innovation to market. The speed at which the innovation enters the market depends on how well it fulfils demand in a practical application. If it does, the next phase can be accelerated within months or years." - WB_16

Green Concrete: Concept Understanding & Current Market Status

According to the quotations, the questioned individuals characterise green concrete as a sustainable material that is safe to use and has a little impact on the environment. Recycled aggregates and other waste products from other sectors, such as blast boiler wastes, can be used to create green concrete. Moreover, it may be produced through lowering CO2 emissions and looking for alternatives to conventional materials. A viable alternative for green concrete is geopolymer concrete. Yet, the cost and performance of green concrete are also issues. Although green concrete shows promise, it is still in its infancy and has just a few uses. Regulation and incentives can encourage the use of green concrete in the building industry.

"Green Concrete is concrete with a lower environmental impact." - WB_3

"I believe that green concrete is made by using a binder derived from waste products of another industry, along with recycled aggregates" - WB_9

"When I think about green concrete, I associate it with nature, low carbon emissions and the impact on the environment. - WB_4

Based on the findings, it appears that the usage of green concrete is expanding in the construction sector, but the switch to more environmentally friendly products and techniques is taking place gradually because of a lack of rules, recommendations, and information. The industry is concentrated on lowering carbon emissions, utilising waste products and recovered resources, and decreasing the environmental effect of concrete. Green concrete has a variety of uses, including creative constructions, infrastructure, 3D printing, and repair materials. Cost, performance, durability, and the absence of standards and norms are some of the issues that still need to be resolved. For constructions that must be watertight or where there is a need to lessen environmental effect, there are ongoing programmes and activities that attempt to promote the adoption of more sustainable concrete alternatives. Although concrete is still a crucial component for many infrastructure projects, there is a rising movement to use green concrete in an effort to reduce the negative environmental effects. Government should provide resources to facilitate the shift to more sustainable materials and technologies. Incentives, such as cost and participation in projects, are needed to make green concrete more appealing to businesses for investment and collaboration.

Stakeholders Power Dynamics

"The government is a major player in the construction industry, primarily because they act as a client for many projects and also as a legislator. They are responsible for making decisions on rules of the game, bringing innovations to markets, and establishing agreements, norms, and standards. This dual role gives the government a significant level of influence in the industry." - EXT_1

"Contractors know that, and the end is all about money." - WB_7

"Demonstration is a crucial aspect of implementing innovative solutions. By showcasing how a solution works in practice, people can see and feel its effectiveness, which builds trust and increases the likelihood of adoption. This is exemplified in the Green village, where people can see other materials and how they work. Convincing everyone from the outset is difficult, but gaining the support of influential professionals can increase the chances of success." - EXT_2

On the basis of the information obtained on this topic, it is unclear who has the most influence over the adoption of innovations in the construction sector. Nonetheless, a number of stakeholders—including customers (particularly government agencies), contractors, maintenance divisions, and senior executives—were noted as having the capacity to exert influence.

If they had the power, some respondents said they would work with clients to ensure that the conditions are right for implementation, increase transparency and collaboration among stakeholders, offer more financial incentives for innovation, and use pilot projects and case studies to demonstrate the efficacy of new solutions.

5.2.3 Green Concrete in practice

Points of application for Green Concrete

"Do you believe green concrete should always be used in new buildings, or are there occasions where it is not an appropriate choice?" is one of the questions the participants were asked during the interviews. The opinions of the participants are varying due to different backgrounds and experience of each individual. Some argue that green concrete may not always be the best option for every case, despite the fact that some other people think it should always be used to promote sustainability and lower carbon emissions. The choice to utilise green concrete can be influenced by elements including the client's motivation, the availability, and the potential dangers connected with innovation. Therefore, whether green concrete should always be used in new construction is not easily answered and should take into account a number of different aspects, including the material's utility, cost, and influence on the environment.

Challenges

"Every solution has its own different barrier, so some of them are very solution specific, but I think the general barrier is the expectation from a relatively conservative market. Innovation is quite difficult to implement in constructions because there are a lot of people keeping it back. It is also justifiable because it is complicated to change the way you build. There needs to be a balance between the level of innovation and the

conservative attitude. From the bottom of the chain, that is how we prioritise the types of innovations in terms of concrete. We start with something that has less risk. So, it means that it takes very long until an innovative solution becomes a normality, it can be 30 years until proven. It is different from other industries. For example, technology is way faster than construction." - EXT_5

"Firstly, cost is a significant factor, and it encompasses more than just monetary expenses. It also includes the time and effort required to complete a task." - WB_5

"The biggest problem is the lack of awareness among people regarding the possibilities and the tested solutions. This is a significant challenge that needs to be addressed." - WB_9

Before green concrete is widely used in building, there are a number of issues that need to be resolved. The challenges mentioned by the interviewed people include lack of laws and standards, unpredictability of long-term behaviour, cost, strength, and durability problems, resistance to change from traditional industry players, and worries about the material. Other issues that need to be resolved include the scarcity of alternatives, the difficulty of scaling up production, and the high investment costs related to innovation. A combination of strategies may be required to lessen the environmental impact of construction, hence there is a need for more education and knowledge about sustainable construction techniques.

Additionally, there are issues with technological viability, regulatory rules, a lack of experience, the availability of local resources, a lack of applications, and worries about social impact. Contractors may find it difficult to use green concrete because of the technical difficulties involved, and the cost can be higher than with conventional concrete solutions. In order to use green concrete effectively, standards and regulations are also necessary, albeit getting stakeholders to adopt them may be difficult. Language limitations, ignorance, and conservatism among cement producers are additional difficulties that must be overcome.

Nonetheless, in order to integrate new technologies like green concrete, the building sector needs to be more adaptable and creative. Green concrete could be used in construction to address sustainability challenges, making it a crucial step towards a more sustainable built environment. In order to attain more sustainable construction methods, the industry can address these issues and overcome opposition to change, encourage innovation, and raise knowledge of and educate about such techniques.

Practical examples of innovations

The data obtained from the discussion sessions provides several practical examples of innovation in various aspects of construction and infrastructure development. One area of innovation involves the use of sustainable materials such as geopolymer concrete, calcinated clay, and polymer concrete with reduced carbon emissions. These materials can replace traditional concrete in building infrastructure, such as tunnels, bridges, and urban furniture.

Another area of innovation involves the reimagining of waste infrastructure in cities, incorporating smart technologies to make them more circular. Inclusion workshops involving the community can also help in the redesign of infrastructure.

There are also recommendations for the use of steel fibre concrete in water-tight structures, bio-based wood buildings as an alternative to concrete for high rises, and the building of bicycle bridges using flax fibre technology.

In terms of sustainability, the data mentions the use of recycled materials and new technologies to reuse or reactivate cement. There is also a mention of implementing environmental impact limits for concrete, which encourages ongoing innovation to reduce impact over time.

Finally, there are mentions of sustainable transportation solutions, such as electric cars, and the development of green hydrogen as a potential sustainable energy source for concrete factories.

Overall, the data shows that there is ongoing innovation in various aspects of construction and infrastructure development towards sustainability and reducing the impact on the environment.

Factors of influence in the decision-making process

Under the context of the discussion, seven areas of influence are identified in the implementation process of green concrete, together with a particular pinpoint factor in each area.

- Cost – Investment: Many quotations stress the significance of cost and investment as a key element in the implementation of green concrete. The financial situation, the necessity for standards to enable cost-effective implementation, and the significant investment costs associated with innovation are all included in this. It is evident that the construction sector works within limited financial constraints, and adopting sustainable methods would necessitate more funding.

  "The use of automation and innovation has advantages. However, there is always a balance between seeing the benefits of innovation and implementing it, as there are high investment costs associated with it. Many companies may not be able to afford it, especially when they are not sure if the innovation can be implemented effectively." - WB_14

- Stakeholders – Client (especially the Government) and Contractor: According to a number of quotes, the contractor's and client's decisions about green concrete play a big part in how it is implemented. The usage of green concrete in projects can be aided or impeded by the goals of the client and the contractor's aim for financial gain. It is also obvious that contractors can only be pressured to use green concrete to a limited degree.

  "The ambitions of the client are also a significant factor. As a result, we often provide advice on sustainable sustainability. However, ultimately, the decision is up to the client." - WB_11

- Sustainability – Environment: An important concern that affects decision-making is how building will affect the environment, especially climate change and biodiversity. Another issue is public opinion, and it is obvious that the environment is what most strongly affects people's choices.

- Innovation – Technology: Although innovation and technology are key forces behind green concrete, its implementation faces difficulties because of the high upfront expenditures and requirement for effectiveness data. To encourage the use of green concrete, many businesses have pilot programmes in place and support innovation.

- Performance – Safety: The effectiveness and safety of green concrete are important aspects that can influence whether it is used in the construction sector. It must be structurally sound, able to withstand environmental deterioration, and secure for use.

- Social Impact – Risk Appetite: Another crucial aspect of green concrete is its social impact, especially related to the risk appetite of the stakeholders. Before investing in big infrastructure projects, it is preferable to start with small projects due to the impact of employing new materials and the danger of failure.

  "Starting with smaller projects is a wise choice compared to investing heavily in a large infrastructure project. This approach allows for better testing of sustainable solutions and helps to identify and mitigate potential risks before scaling up to larger projects." - WB_8

- Openness – Collaboration and Cooperation: Finally, several quotes emphasise the importance of openness in terms of collaboration and cooperation between stakeholders, including clients, contractors, and innovative startups, to promote the adoption of green concrete. This includes listening to stakeholders, leaving room for innovation, and having open discussions about better solutions.

  "When submitting a tender, it is essential to ensure that the design is not overly specific to a single solution that only one contractor can provide. This helps to promote competition and allows for a broader range of options for the client to choose from." - WB_11

  "We aim to collaborate with other stakeholders to set an example and encourage them to adopt sustainable practices in the construction industry." - EXT_5

Possible Solutions

Towards the end of each interview, the participants were asked about how would they solve the problem of implementing green concrete in construction projects.

To promote sustainability in construction, contractors should be encouraged to embrace sustainable solutions, and incentivising sustainability through a carbon tax on CO2 emissions is an option. Bio-based materials and circularity should be embraced, while starting with smaller projects, providing transparency, and demonstrating successful implementation can build trust and support. High-level professionals should be involved, and performance-based requirements should be created to encourage innovation. Quality control standards for sustainability should also be developed. Early involvement of stakeholders and sharing information can lead to more sustainable practices. Investing in technology for efficient recycling can also promote sustainability.

To further promote sustainability, redesigning concrete to be reusable and using green hydrogen in concrete factories can be helpful, along with conducting experiments and monitoring them closely. Shifting towards a sustainable mindset in building design and providing consultancy to clients can increase their awareness of green concrete possibilities and risks. Long-term benefits should be prioritised over short-term gains, and projects should be planned carefully with sustainability in mind. Prefab construction can create ideal circumstances for green concrete. Investing in dedicated applications for green concrete and involving clients in its implementation are important. Strategic niche management and testing specific elements can minimise risks and disruptions. Government subsidies, using local materials, and communicating sustainable practices to clients are important. Rethinking traditional mass construction methods, supporting innovation, conducting pilots, using certifications, and innovating construction systems can all promote sustainability.

Chapter 6

Discussion & Conclusion

This chapter serves as an opportunity to create an in-depth interpretation of the results and to finally draw a conclusion on the outcome of this research. It includes an overview of the findings resulted from the literature review, the online survey and the semi-structured interviews and how these findings relate to the main research question, the four sub-research questions and the hypothesis of this research. A strategy-development framework will be illustrated based on the concluding thoughts, which will serve as a practical suggestion on how to aid the implementation process of green concrete solutions in construction projects.

6.1 Hypothesis, Research Questions & Methodology

The adoption of green concrete solutions in construction projects can significantly contribute to achieving sustainability goals by reducing environmental impact and promoting the efficient use of natural resources. However, the implementation of green concrete solutions faces several challenges related to economic, environmental, and societal factors, which must be addressed to ensure the widespread adoption of these solutions in the industry. By identifying and addressing these challenges, construction professionals can effectively integrate green concrete solutions into their projects, promoting sustainable development and mitigating the negative effects of the construction sector on the environment.

The main research question around which this graduation project revolves is formulated as *"How can green concrete solutions be implemented in construction projects to achieve and promote sustainability, considering the challenges and limitations of adopting innovations in the industry?"*, but in order to simplify the thought process, four sub-research questions are formulated. *What is the definition and significance of green concrete in the construction industry, considering its potential to promote sustainability?*; *What are the most common challenges and limitations faced by construction professionals when implementing green concrete solutions in their projects, and how can these be addressed effectively?*; *What are the key factors that influence the decision to adopt green concrete solutions in construction projects, and how can these be leveraged to promote the widespread implementation of these solutions?*; *What are the possibilities in terms of practices and strategies for integrating green concrete solutions into the design and construction process, ensuring that they are seamlessly integrated into the project and meet the required performance standards?*.

To answer the research questions, a mixed methodology was approached to provide an in-depth understanding of green concrete as an innovation in the current construction market. The literature review constitutes the theoretical core of this research, defining the concept itself, but also describing the dynamic of an innovation from concept to application, and the additional parameters that drive the implementation process as challenges and influencing factors. The online survey provided both quantitative and qualitative data for this research from a larger population in a short period of time. The survey results provided valuable insights into the concept of green concrete and revealed the opinions of experts regarding the innovation. Moreover, it also highlighted their personal beliefs about the challenges that hinder the successful implementation of green concrete in construction projects. The semi-structured interviews were conducted after the literature review and the online survey results were analysed. The interviews followed a flexible discussion approach and focused on the factors that influence the decision-making process for selecting sustainable construction materials. Additionally, the interviews aimed to identify successful examples and innovative solutions that have been applied in real-world projects.

6.2 Discussion on Key Findings

This research was performed to investigate the implementation process of green concrete into practical construction applications in order to achieve and promote a sustainable development of the industry, considering the factors that hinder the implementation process of the innovations. The findings resulted from the literature, in-house online survey, and the semi-structured interviews provided valuable information into the definition, significance, challenges, and possible solutions from promoting green concrete as a reliable construction material.

Combining the definitions of Johnsson et al. (2020); Baikerikar (2014); Suhendro (2014), green concrete is a sustainable construction material that incorporates eco-friendly elements throughout its life cycle, including the design, building, and maintenance phases. It uses recycled materials in its composition and avoids processes that harm the environment. With its high performance and long-lasting sustainability, green concrete plays a crucial role in achieving sustainability goals by minimising environmental impact and promoting resource efficiency in the construction industry. To further develop the existing definitions, this research adds that green concrete represents a sustainable material that can be characterised by a reduced cement content, incorporation of recycled minerals, lower energy and water consumption, and longer lifespan, and it has the ability to promote environmental, social, and economic sustainability in the construction market.

The literature study underlined the importance of performing an Environmental Impact Assessment (EIA) and a Life Cycle Sustainability Analysis (LCSA) to determine the impact of green concrete on the environment and socio-economic factors. Even though green concrete comes with benefits as waste reduction (Badraddin et al., 2021), lower carbon footprint and energy efficiency (Suhendro, 2014), its implementation faces many challenges, including a conservative attitude of the industry, supply chain disruptions, and technological and legislative issues (Amato, 2013).

The online survey conducted inside the company highlighted a moderate familiarity feeling with the concept among the respondents, emphasising the fact that there is a need for more education and awareness. The environment is the factor that influences the most in the decision-making process out of the 3 sustainability dimensions, followed by society and lastly economy. The factor analysis performed on the data assessed several challenges to innovation, including resource and capacity constraints, market related issues, lack of leadership and vision, collaboration and communication issues, and time-related problems.

The 19 semi-structured interviews with different construction specialists confirmed the significance of green concrete as a sustainable material and its benefits on sustainability. However, implementation challenges were highlighted such as cost, performance, durability, and lack of norms and standards. The influencing factors in relation to the implementation were mentioned, including cost and investment, client and contractor decisions, sustainability and environment, innovation and technology, performance and safety, social impact, and openness and collaboration.

The findings confirm the hypothesis that the adoption of green concrete solutions can significantly contribute to achieving sustainability goals by reducing environmental impact and promoting the efficient use of natural resources, in light of the main research question and the sub-research questions. However, the implementation of green concrete solutions has a number of problems linked to economic, environmental, and societal concerns that must be solved in order for these solutions to be widely adopted in the industry. By identifying and resolving these limitations, building professionals can effectively include green concrete solutions into their projects, supporting sustainable development and lessening the negative environmental effects of the construction industry.

The findings reveal that the best practises and tactics for integrating green concrete solutions into the design and construction process include collaboration between all possible stakeholders related to GC, education in terms of the possibilities and capacities of GC, and awareness-building at a multi-industry level, as well as regulatory incentives and investment in research and development. These techniques can assist construction professionals in overcoming the problems and limits associated with implementing green concrete in the industry, as well as promoting the successful deployment of new sustainable materials and technologies and fostering sustainable development in the construction sector.

6.3 Implications of the Study

The results of this study have significant ramifications for future green concrete and sustainable building research, policy, and practise. This research helps to develop methods for encouraging sustainable construction practises and reducing the damaging environmental effects of the construction sector by addressing the constraints and difficulties of putting green concrete solutions into practise. By examining the factors influencing the decision-making process for choosing sustainable construction materials, this research also fills a gap in the literature and offers helpful advice for construction professionals on how to incorporate green concrete solutions into their projects.

6.4 Green Concrete Integration Model

Based on a holistic approach, the GCIM (Green Concrete Integration Model) illustrated in Figure 6.1, integrates all the factors responsible for the implementation of GC in construction projects following the path of innovation towards a practical application. The framework compiles all the findings resulted from the literature study, online survey, and the semi-structured interviews and focuses on the overlap between the Concept Development and Implementation segments from the Flexible Implementation Model of Innovation from Figure 2.5.

The GCIM is divided in two dimensions, divergent where discovery and exploration happens and convergent where the implementation of innovation starts getting shape, and it is constantly monitored and evaluated. That being said, the model starts from the premises that the GC mixture has already reached at least level 4 on the TRL scale. Level 4 on the TRL scale represents a stage where the technology has been demonstrated in a relevant environment. This means that the technology has been tested in conditions that closely resemble real-world situations and has shown its ability to perform its intended function.

The spiral model is an effective strategy for project implementation frameworks, and its efficiency comes from the fact that iteration is a key component of it. The spiral model, in contrast to more rigid, linear models, represents a cycle of ongoing improvement and advancement. Every cycle, or iteration, is a different stage of the project, encompassing its expansion and evolution. When applying novel technologies or procedures, like the green concrete mentioned in this thesis, this progression becomes especially crucial.

The spiral model's natural emphasis on feedback and learning is one of its fundamental characteristics. After each spiral, the innovation has the chance to apply fresh insights and learnings, providing a mechanism for ongoing improvement. The model's capacity for accommodating change is also a reflection of its adaptability. The spiral model allows for revisions as the project develops, and additional information is learned, making it extremely resilient in the face of fresh information or unforeseen difficulties.

Since the literature provides four classes of challenges, technical, economic, socio-cultural, and regulatory, see Table 2.3.2, the GCIM separates the implementation process into six distinct steps: identification, estimation, planning, testing and refining, scale-up, and long-term monitoring. This can help with the early identification of possible occurring issues and allows for modifications in the implementation path. The six steps are arranged in a spiral manner, as the early design lock-down is not possible and adjustments are needed along the way. The continuous spiralling effect is driven mostly by the market influence and the outcome of each step.

As resulted from the survey, personal traits and generalised views are defining the market influence. Different familiarity levels, concept understanding, innovation expectations, and public dynamics as openness towards the new and sustained efforts for better practises, are making the implementation process very complex. Therefore, the step's division of the GCIM can help with complexity of the process by managing in each stage the corresponding challenges.

Combining the findings of the survey with the semi-structured interviews, the market presents an opportunistic context for the adoption of GC, but it needs a systematic manner of approaching the issue. An advanced stakeholder management is needed to avoid the short-term thinking issue, while environmental, social, and economic factors need to be constantly monitored.

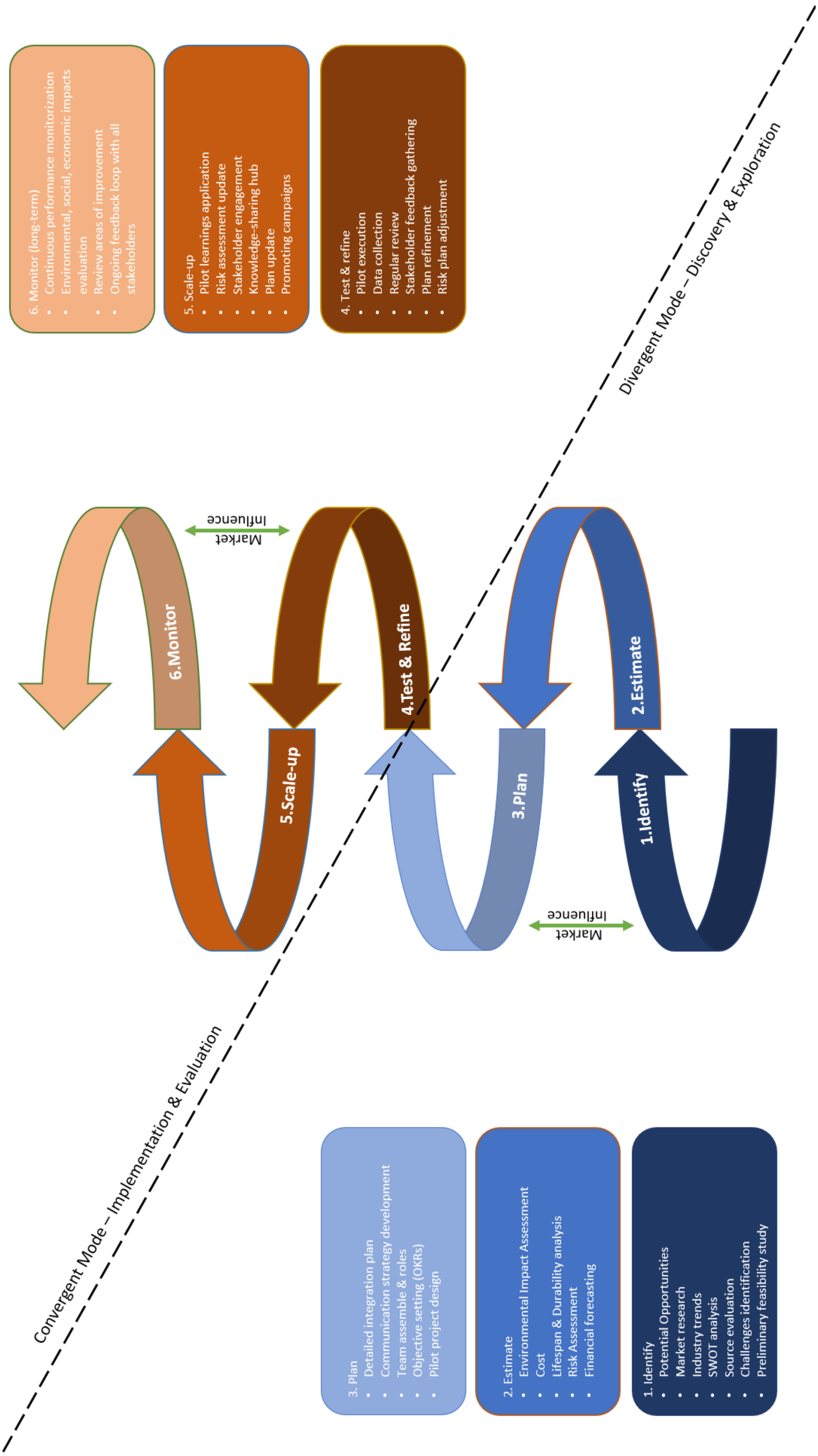

Figure 6.1: Green Concrete Integration Model; Source: Author

The six steps developed for this project, as mentioned previously, are in a spiralling loop due to the dynamic context of the innovative process. Each step includes a series of additional activities that can vary in given scenarios.

1. Innovation identification: The initial step in the implementation process focuses on establishing a strong foundation for the successful integration of green concrete into construction projects. This step involves a comprehensive approach that begins with conducting market research to identify potential opportunities for applying green concrete. By analysing industry trends and regulatory requirements, valuable insights are gained regarding the current landscape and market dynamics. A SWOT analysis is then performed to identify the strengths, weaknesses, opportunities, and threats related to implementing green concrete. An important aspect of this step is the evaluation of sources, which involves assessing the availability and reliability of raw materials and green concrete technologies. This evaluation aims to ensure a sustainable and efficient supply chain by assessing the quality of the required raw materials and technology. Additionally, potential obstacles to implementing green concrete are identified, and preliminary feasibility studies are conducted to assess the project's viability and alignment with the defined goals. Figure 6.2 illustrates the sub-activities of step 1, and showcases the origin of the information from the corresponding sub-research questions.

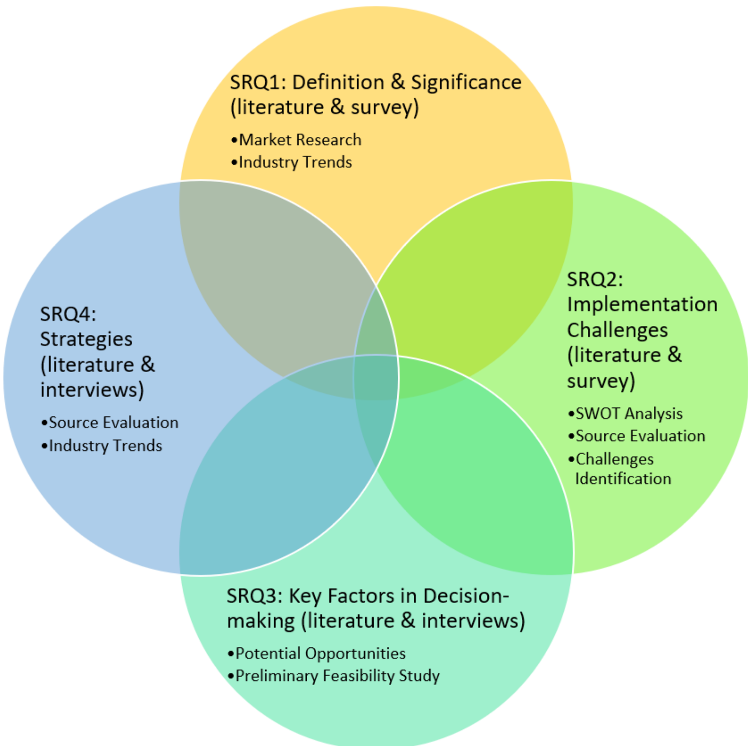

Figure 6.2: Step 1 of GCIM: Identify; Source: Author

2. Innovation estimate assessment: The second step in the implementation process, referred to as "Estimate", focuses on obtaining a comprehensive understanding of the resources and impacts involved in the implementation of green concrete. This step begins by estimating the costs associated with the project, which encompasses materials, labour, technology, and other essential elements. Alongside cost estimation, it also evaluates the potential environmental benefits of using green concrete by quantifying factors such as reduced CO_2 emissions and resource utilisation.The analysis in this step extends to assessing the lifespan and durability of green concrete compared to traditional materials, as this evaluation is crucial for determining the long-term advantages. Additionally, conducting a thorough risk assessment is an integral part of this step, involving the identification and analysis of potential risks that could impact the project. Lastly, financial predictions are made to anticipate the financial impact and potential savings that may arise from regulatory incentives or the extended lifespan of green concrete. This step plays a vital role in facilitating informed decision-making and establishing a realistic and sustainable project plan. Figure 6.3 illustrates the sub-activities of step 2, and showcases the origin of the information from the corresponding sub-research questions.

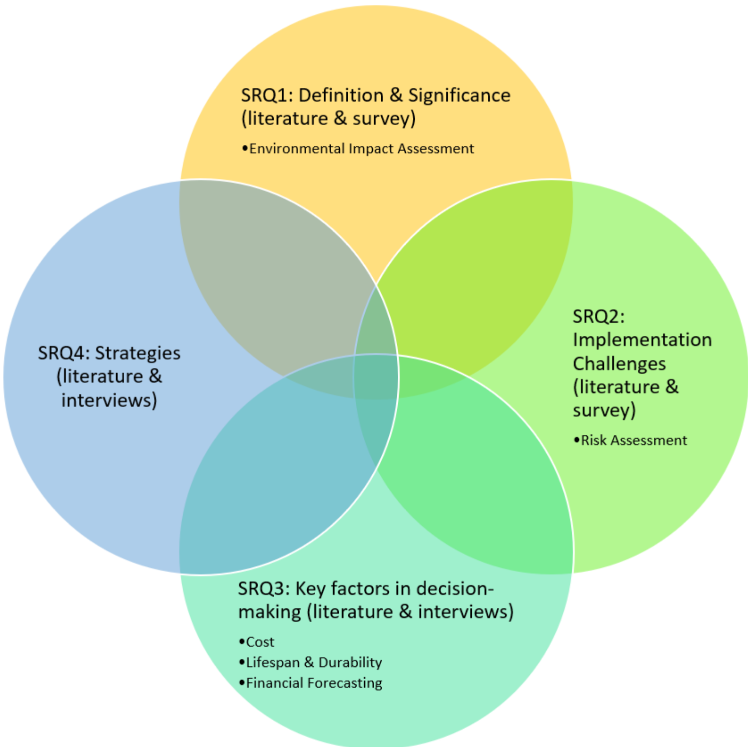

Figure 6.3: Step 2 of GCIM: Estimate; Source: Author

3. Implementation planning: In the third step of the implementation process, which is titled “Plan”, the focus shifts towards developing a detailed road-map for incorporating green concrete into construction projects. This stage builds upon the insights gained from the earlier discovery and estimation stages. A comprehensive project plan is created, outlining specific timelines, milestones, and resource allocation. A communication strategy is established to ensure that all stakeholders are well-informed and actively engaged throughout the project. Assembling a competent team with clearly defined roles and responsibilities is essential for ensuring accountability and efficiency. Additionally, a risk management plan is devised to proactively address any potential risks identified during the estimation phase. The Objectives and Key Results (OKRs) are established to provide tangible targets that guide the project's progress. Furthermore, a pilot project is designed to conduct initial testing and validation of the green concrete implementation. The planning phase is of utmost importance, as it establishes the foundation for a systematic and effective execution of the project. Figure 6.4 illustrates the sub-activities of step 3, and showcases the origin of the information from the corresponding sub-research questions.

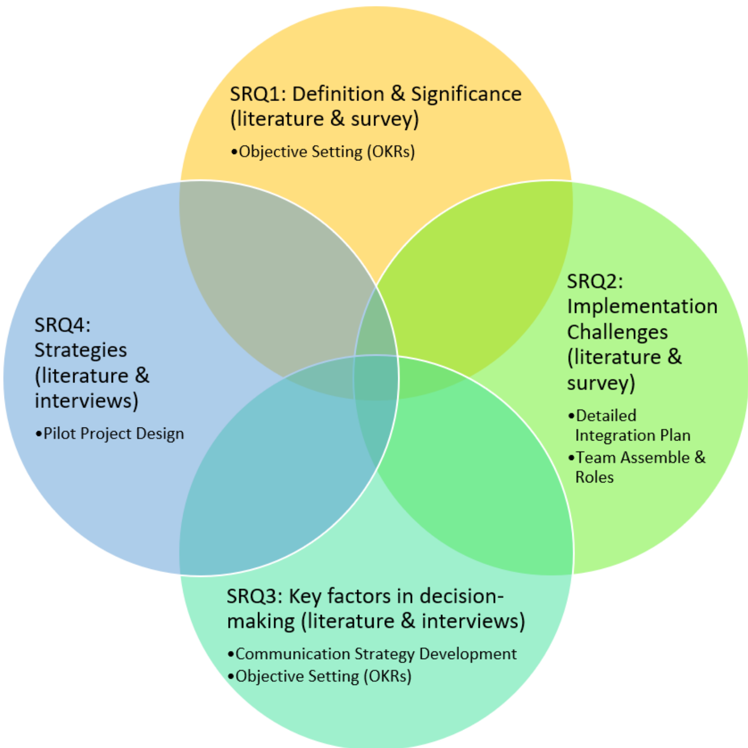

Figure 6.4: Step 3 of GCIM: Plan; Source: Author

4. Testing and refining: The project moves from planning to action in the fourth level, "Test and Refine", where the emphasis is on confirming the usefulness of putting green concrete into practise. In order to test the usage of green concrete on a lesser scale, a pilot project that was planned during the planning stage is implemented. During this phase, rigorous data on performance, cost, durability, and environmental impact are gathered. The pilot project is regularly reviewed, enabling the team to compare results to the predetermined goals. The gathering of stakeholder feedback, which offers insights into real-world experiences and opinions, is a crucial component of this step. The project plan is adjusted using the data and feedback gathered. This could entail improving processes to improve performance, reallocating resources, or changing timetables. The risk management strategy is also reviewed and modified in light of actual experiences and data. Before scaling up, the "Test and Refine" process is an essential feedback loop that enables optimisation and makes sure the project is based in reality and is effective. Figure 6.5 illustrates the sub-activities of step 4, and showcases the origin of the information from the corresponding sub-research questions.

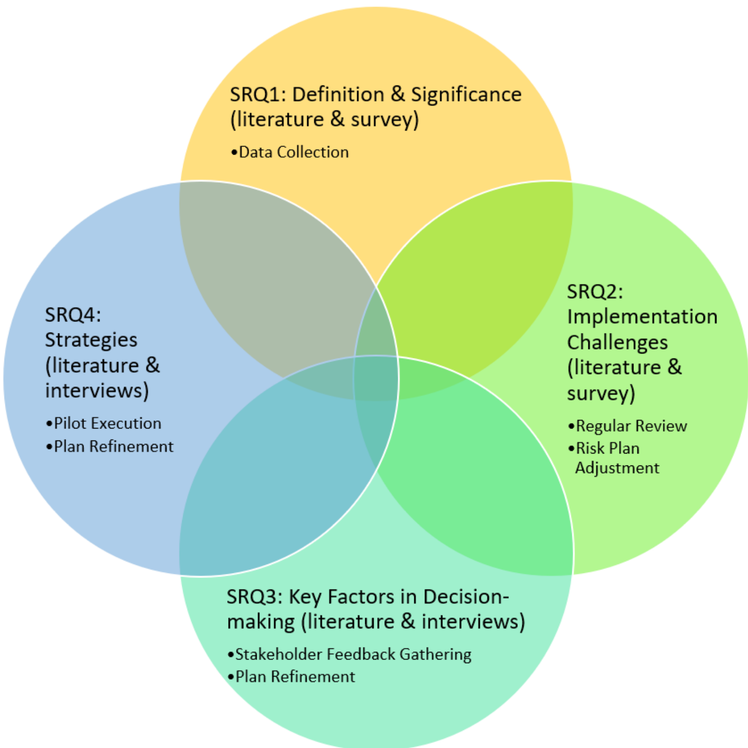

Figure 6.5: Step 4 of GCIM: Test & Refine; Source: Author

5. Scale-up: The project develops from the pilot phase to the full-scale application of green concrete in the fifth step, named “Scale-up”. The learnings and improvements made throughout the testing phase inform this shift. It’s crucial to reevaluate risks during scale-up and make the required changes to the risk management plan, taking into account the larger scale of activities. In order to successfully communicate information on project progress, communication methods should be optimised. Constant involvement with stakeholders is still essential. To account for the bigger scale, the project plan, including prices and schedules, may need to be updated. Logistics must be taken into consideration, and supply networks must be strong and able to meet the rising demand for goods and resources. In order to successfully implement the project, it is crucial to retain diligence and adaptability during the crucial scaling up phase, where the initiative must show its viability and usefulness on a bigger scale. Figure 6.6 illustrates the sub-activities of step 5, and showcases the origin of the information from the corresponding sub-research questions.

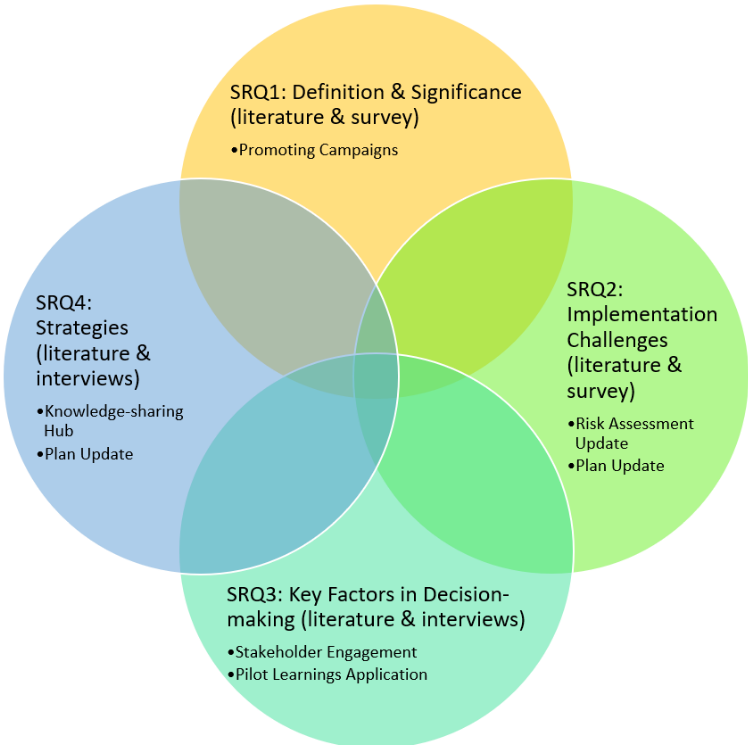

Figure 6.6: Step 5 of GCIM: Scale-up; Source: Author

6. Long-term monitoring and evaluation: The project enters a phase of continual supervision in the sixth and final step, “Monitor”, to assure the long-term success and effectiveness of the green concrete implementation. The crucial aspect of this phase is performance monitoring, which entails the regular gathering and analysis of information on the robustness, economy, and environmental impact of the green concrete. To make sure that the project complies with legal requirements and industry best practises, compliance audits are carried out. Continuous data collection helps identify areas for improvement and enables informed decision-making. To handle new difficulties, the risk management plan is regularly reviewed and updated. Stakeholder communication is still a top concern since it promotes transparency and cooperation. Lastly, staying abreast of advances in the field of green concrete is essential for the potential incorporation of new technologies or practices. The monitoring phase is crucial in securing the long-term viability and sustainability of the project. Figure 6.7 illustrates the sub-activities of step 6, and showcases the origin of the information from the corresponding sub-research questions.

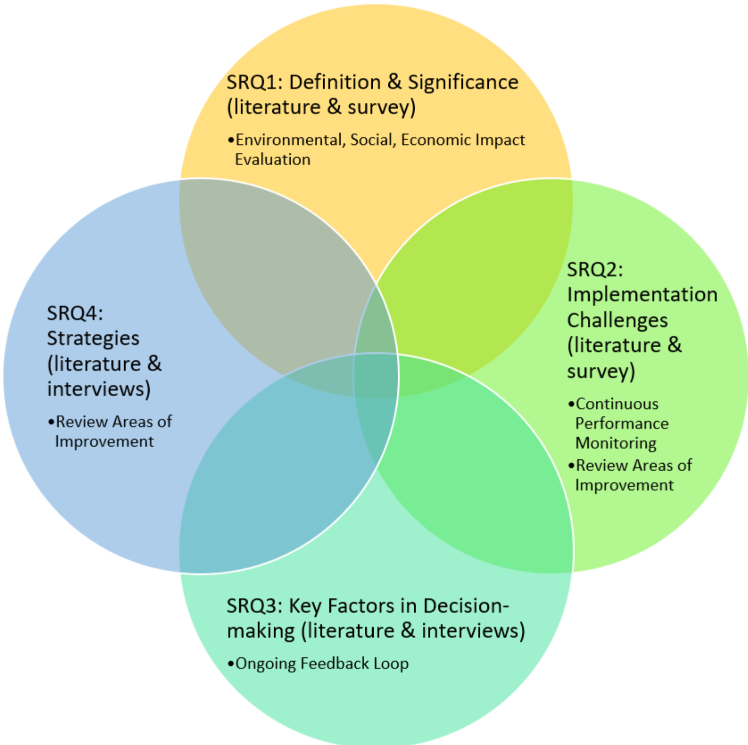

Figure 6.7: Step 6 of GCIM: Long-term Monitoring; Source: Author

The GCIM illustrates a general approach on the concept implementation. As aforementioned, the spiral shape of the framework suggests the continuous growth and the dynamic environment. To reduce the generalisability, a different shape of the framework must be adopted for the implementation of specific green concrete mixtures. Therefore,

Figure 6.8 rearranges the 6 implementation steps linearly that would reach a market introduction. The Specific Green Concrete Integration Model is based on the Flexible Model, Figure 2.5, developed by Meyer (1998), but tailored in correspondence to the GCIM.

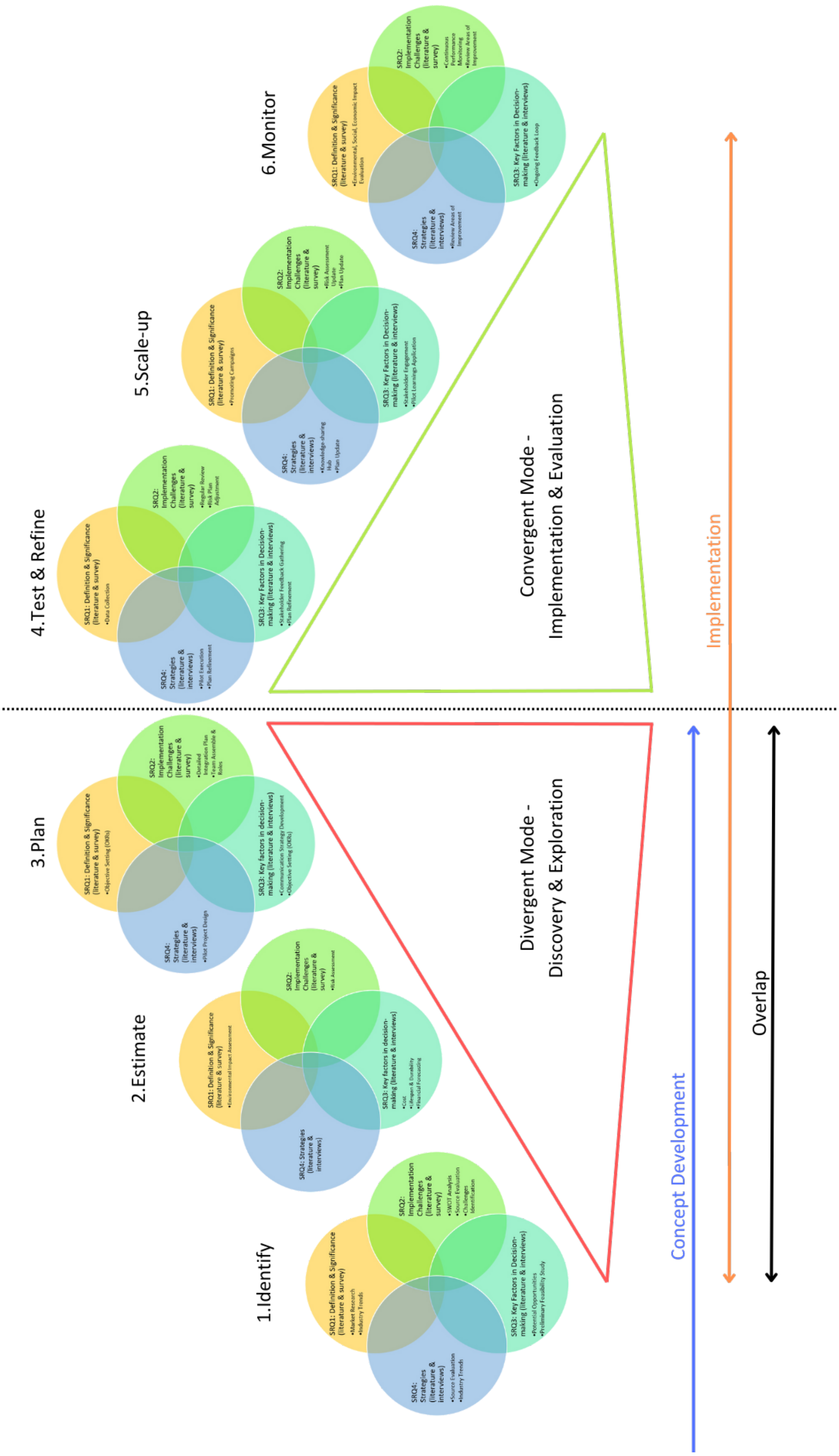

Figure 6.8: Specific Green Concrete Integration Model; Source: Author

6.5 Limitations of Study

As explained in Chapter 3.2, the methodology used for this research includes a literature study, an online survey, and a series of semi-structured interviews. Given the mixed methodology, multiple limitations can interfere with the outcome of the research. Sample size and representation: The number of survey respondents and interview participants was limited, which may impair the findings' generalisability. Participants do not reflect the entire construction sector, as they have specific expertise and interests in the industry. Subjectivity: The semi-structured interviews were interpreted in a qualitatively by the interviewee. Qualitative interpretation is subjected to personal experiences, opinions, and biases of the researcher. Bias: The online survey may be prone to response bias, in which respondents give socially acceptable or desirable answers rather than their genuine feelings. This could have an impact on the accuracy of the findings. Scope limitation of the literature study: The review of the literature may not include all important research on green concrete and construction practises. More recent studies or research from other fields could have an impact on the overall understanding of the topic.

To effectively address these limitations, a larger sample size with more diversity could be analysed. Next to that, different methodologies could be selected and vaster and or newer literature could be included in the study in a greater project time frame.

6.6 Conclusion

In conclusion, this research provides valuable insights into the implementation process of green concrete solutions in construction projects and the challenges and limitations associated with their adoption. The results support the idea that implementing green concrete solutions can considerably help achieve sustainability goals by encouraging not only efficient use of natural resources and minimising environmental effect but also social and economic growth. With this all-encompassing approach to sustainability, green concrete solutions are guaranteed to have a beneficial impact on each of the three dimensions, leading to a thorough and balanced advancement towards a more sustainable building industry. However, the implementation of green concrete solutions faces several challenges related to economic, environmental, and societal factors, which must be addressed to ensure the widespread adoption of these solutions in the industry. By identifying and addressing these challenges, construction professionals can effectively integrate green concrete solutions into their projects, promoting sustainable development, and mitigating the negative effects of the construction sector on the environment.

6.7 Recommendations

The study's findings have relevant implications for future research, policy, and practise in green concrete and sustainable construction. Based on these findings, the following recommendations can be stated:

Future research: Further research should concentrate on solving the limitations mentioned in Section 6.5, such as greater sample size and professional diversity, undertaking experimental or observational investigations, and updating the existing literature regularly to integrate new findings. Researchers could also investigate the long-term performance and environmental impact of green concrete solutions in real-world projects, as well as finding a specific solution for each of the challenges identified.

Policy development: Benefits and legislation to encourage the use of green concrete should be implemented by policymakers. This could mean tax benefits, subsidies, or grants for green concrete projects, as well as stronger environmental regulations that push the use of sustainable materials. Also, developing standards, norms, and quality control methods is crucial in the adoption of green concrete.

Education and awareness: To increase awareness of the benefits and possible applications of green concrete, industry stakeholders should invest in education and knowledge-sharing programmes. This could include conducting workshops, training programs, and conferences, as well as encouraging academic institutions and industrial collaboration to bridge the knowledge gap and stimulate innovation.

Collaboration and partnerships: To tackle the challenges that come with the use of green concrete, stakeholders such as construction companies, material suppliers, and others should work together. To implement innovations and adhere to best practices, this can entail establishing public-private partnerships, assembling multidisciplinary teams, and working together on research and development projects.

Integrating sustainability dimensions: When implementing green concrete solutions in construction projects, decision-makers should consider all three sustainability dimensions: environment, society, and economy. This comprehensive approach will help ensure that green concrete solutions are not only environmentally friendly but also socially responsible and economically viable.

Focus on innovation and technology: The development of green concrete should be supported by investments in research and development to address difficulties with cost, performance, durability, and technology. Investing in cutting-edge recycling technology, investigating bio-based materials, and creating novel concrete combinations and additives that improve the functionality and sustainability of green concrete are a few examples of what this could include.

By implementing these recommendations, the construction industry can work towards achieving greater sustainability and successfully adopting green concrete solutions in future projects. This will help address the research question and contribute to mitigating the negative environmental impacts of the construction sector while promoting sustainable development.

Bibliography

Abusalah, M. and Tait, J. (2018). Innovation Management in Construction - Practical Approach.

Agarwal, N. and Garg, N. (2018). A Research on Green Concrete.

Agarwal, R., Chandrasekaran, S., and Sridhar, M. (2022). Imagining construction's digital future.

Ahmad, I., Russell, J. S., and Abou-Zeid, A. (1995). Information technology (IT) and integration in the construction industry. *Construction Management and Economics*, 13(2):163–171.

Ahmed, M., Qureshi, M. M., Mallick, J., and Kahla, N. B. (2019). Selection of Sustainable Supplementary Concrete Materials Using OSM-AHP-TOPSIS Approach. *Advances in Materials Science and Engineering*, 2019:1–12.

Al-Ashmori, Y. Y., Othman, I., Rahmawati, Y., Amran, Y. M., Sabah, S. A., Rafindadi, A. D., and Mikic, M. (2020). BIM benefits and its influence on the BIM implementation in Malaysia. *Ain Shams Engineering Journal*, 11(4):1013–1019.

Al-Hamrani, A., Kucukvar, M., Alnahhal, W., Mahdi, E., and Onat, N. C. (2021). Green Concrete for a Circular Economy: A Review on Sustainability, Durability, and Structural Properties. *Materials*, 14(2):351.

Alqahtani, F., Abotaleb, I. S., and ElMenshawy, M. (2021). Life cycle cost analysis of lightweight green concrete utilizing recycled plastic aggregates. *Journal of building engineering*, 40:102670.

Amato, I. (2013). Green cement: Concrete solutions. *Nature*, 494(7437):300–301.

Anderson, M. (2022). Topics in Sustainability: Green Concrete & Concrete Alternatives.

ArchDaily (2022). 3D Printing with Low-Carbon Concrete: Reducing CO2 Emissions and Material Waste.

Asher, S., Garg, T., and Novosad, P. (2020). The Ecological Impact of Transportation Infrastructure. *The Economic Journal*, 130(629):1173–1199.

Badraddin, A. K., Rahman, R. A., Almutairi, S. M., and Esa, M. (2021). Main Challenges to Concrete Recycling in Practice. *Sustainability*, 13(19):11077.

Baikerikar, A. (2014). A Review on Green Concrete. *Journal of emerging technologies and innovative research*, pages 472–474.

Bamigboye, G., Ademola, D., Kareem, M. O., Orogbade, B. O., Odetoyan, A., and Adeniyi, A. D. (2022). Durability assessment of recycled aggregate in concrete production. *Elsevier eBooks*, pages 445–467.

Belton, B. P. (2021). Building's hard problem - making concrete green.

Bosch Global, B. (2022). Going all-out to achieve a green footprint.

Britannica, E. (1999). Cement — Definition, Composition, Manufacture, History, & Facts.

Bruin, J. (2011). newtest: command to compute new test @ONLINE.

Brundtland, G. H. (1991). Our common future. *Earth and Us*, pages 29–31.

BuilderSpace (2022). Modular Construction: 16 Pros and Cons.

Carbonara, N. and Pellegrino, R. (2020). The role of public private partnerships in fostering innovation. *Construction Management and Economics*, 38(2):140–156.

Carey, A. (2023). Importance of Marketing Strategy for a Construction Company.

Castañeda, D. I. and Cuéllar, S. B. (2020). Knowledge sharing and innovation: A systematic review. *Knowledge and Process Management*, 27(3):159–173.

Caves, R. W. (2004). Encyclopedia of the City. *Routledge eBooks*.

Charlott, C. (2022). Revealed: The importance of strategic planning in construction companies and projects.

Chauhan, K., Peltokorpi, A., Lavikka, R., and Seppänen, O. (2019). Deciding Between Prefabrication and On-Site Construction: A Choosing-by-Advantage Approach. *Annual Conference of the International Group for Lean Construction*.

Chen, L., Zhang, Y., Wang, L., Ruan, S., Chen, J., Li, H., Yang, J., Mechtcherine, V., and Tsang, D. C. (2022). Biochar-augmented carbon-negative concrete. *Chemical Engineering Journal*, 431:133946.

Chirumalla, K. (2017). Clarifying the feedback loop concept for innovation capability: A literature review. In *Proceedings of the XXVIII ISPIM Innovation Conference*.

Constructor, T. (2023). Exploring the Benefits and Challenges of Modular Construction.

Cote, C. (2020). Why Is Strategic Planning Important? .

Cotten, S. R., Tashakkori, A., and Teddlie, C. (1999). Mixed Methodology: Combining Qualitative and Quantitative Approaches. *Contemporary Sociology*, 28(6):752.

Crawford, M. (2022). A roadmap to reducing CO2 emissions in concrete manufacturing .

Daniel, S. E., Tsoulfas, G. T., Pappis, C. P., and Rachaniotis, N. P. (2004). Aggregating and evaluating the results of different Environmental Impact Assessment methods. *Ecological Indicators*, 4(2):125–138.

Davis, C. (2019). Carbon Capture and Storage (CCS): Advantages, Disadvantages, and Trends.

Di Maria, A., Eyckmans, J., and Van Acker, K. (2018). Downcycling versus recycling of construction and demolition waste: Combining LCA and LCC to support sustainable policy making. *Waste Management*, 75:3–21.

Digvijay, P. and Onkar, S. (2022). Ready-Mix Concrete Market Size, Trends, Forecast 2030.

Dong, B., Han, N., Zhang, M., Wang, X., Cui, H., and Xing, F. (2013). A MICRO-CAPSULE TECHNOLOGY BASED SELF-HEALING SYSTEM FOR CONCRETE STRUCTURES. *Journal of Earthquake and Tsunami*, 07(03):1350014.

Duodu, B. and Rowlinson, S. (2021). Opening Up the Innovation Process in Construction Firms: External Knowledge Sources and Dual Innovation. *Journal of the Construction Division and Management*, 147(8).

Elis, D. (2021). Global construction to grow 35% in next 10 years.

Ellis, G. (2022). 8 Innovations that Will Change Construction As We Know It.

Fattah, K. P., Al-Tamimi, A. K., Hamweyah, W. M., and Iqbal, F. (2017). Evaluation of sustainable concrete produced with desalinated reject brine. *International journal of sustainable built environment*, 6(1):183–190.

Flick, U. (2018). *An Introduction to Qualitative Research*. SAGE.

Galindo, G. (2021). Innovative Construction, 12 innovations for the future.

Garg, C. and Jain, A. (2014). Green concrete: Efficient & eco-friendly construction materials. *International Journal of Research in Engineering & Technology*, 2(2):259–264.

George, T. (2022). Semi-Structured Interview — Definition, Guide, Examples.

Gower, L. (2022). The ten barriers to innovation.

Griffin, C., Knowles, C. K., Theodoropoulos, C., and Allen, J. H. (2010). Barriers to the implementation of sustainable structural materials in green buildings. *CRC Press eBooks*, pages 369–370.

Guest, S. (2021). The Construction Industry Is Getting Greener: Why, How, And What's Changing?

Gürel, S. and Tat, M. (2017). SWOT ANALYSIS: A THEORETICAL REVIEW. *The Journal of International Social Research*, 10(51):994–1006.

Hart, S. L. and Milstein, M. B. (1999). Global Sustainability and the Creative Destruction of Industries. *Sloan Management Review*, 41(1):23–33.

Hassan, A., Arif, M., and Shariq, M. (2019). Use of geopolymer concrete for a cleaner and sustainable environment – A review of mechanical properties and microstructure. *Journal of Cleaner Production*, 223:704–728.

Hayes, M. (2023). How construction can make the switch to low-carbon concrete.

Heincke, S., Maksimainen, J., and Reiter, S. (2023). Decarbonizing cement and concrete value chains: Takeaways from Davos.

Henderson, R. M. and Clark, K. B. (1990). Architectural Innovation: The Reconfiguration of Existing Product Technologies and the Failure of Established Firms. *Administrative Science Quarterly*, 35(1):9.

Hill, C. (2013). Green Building Codes and Concrete? A Great Combination!

HOUSE, C. (2018). Overcoming Barriers to Deployment of Low-carbon Cement and Concrete.

Hundertmark, T., Reiter, S., and Schulze, P. (2022). Green growth avenues in the cement ecosystem.

Insights, F. B. (2021). Precast Concrete Market Size, Share & COVID-19 Impact Analysis, By Product Type (Building Components, Transportation, Water & Waste Handling, and Others), By End-Use (Residential, and Non- Residential) and Regional Forecast, 2021-2028.

Janse, R. J., Hoekstra, T., Jager, K. J., Zoccali, C., Tripepi, G., Dekker, F. W., and Van Diepen, M. (2021). Conducting correlation analysis: important limitations and pitfalls. *Ndt Plus*, 14(11):2332–2337.

Jin, R. and Chen, Q. (2013). An investigation of current status of "green" concrete in the construction industry. *49th ASC Annual International Conference Proceedings*, page 0.

Johansen, A., Ekambaram, A., Landmark, A. D., and Eik-Andresen, P. (2015). Why is it difficult to exploit opportunities in projects?

Johnsson, F., Karlsson, I. K., Rootzén, J., Ahlbäck, A., and Gustavsson, M. (2020). The framing of a sustainable development goals assessment in decarbonizing the construction industry – Avoiding "Greenwashing". *Renewable & Sustainable Energy Reviews*, 131:110029.

Jonkers, H. M. (2007). Self healing concrete: a biological approach. *Self healing materials: an alternative approach to 20 centuries of materials science*, pages 195–204.

Juenger, M. C., Winnefeld, F., Provis, J. L., and Ideker, J. H. (2011). Advances in alternative cementitious binders. *Cement and Concrete Research*, 41(12):1232–1243.

Kenai, S. (2018). Recycled aggregates. *Elsevier eBooks*, pages 79–120.

Kirsner, S. (2018). The Most Commonly Cited Barriers to Innovation in Large Companies? Internal Politics.

Kotzé, L. J., Kim, R. E., Burdon, P., du Toit, L., Glass, L.-M., Kashwan, P., Liverman, D., Montesano, F. S., Rantala, S., Sénit, C.-A., Treyer, S., and Calzadilla, P. V. (2022). Planetary Integrity. *The Political Impact of the Sustainable Development Goals*, pages 140–171.

Lawlor, B. (2019). 4 elements of an effective innovation process.

Lee, S. (2021). Concrete Still a Barrier to Climate-Friendly Infrastructure Plan.

Lehne, J. and Preston, F. (2018). Making Concrete Change Innovation in Low-carbon Cement and Concrete. *The Royal Institute of International Affairs*.

Lewith, G. T., Jonas, W. B., and Walach, H. (2010). *Clinical Research in Complementary Therapies E-Book*. Elsevier Health Sciences.

Liew, K., Sojobi, A., and Zhang, L. (2017). Green concrete: Prospects and challenges. *Construction and Building Materials*, 156:1063–1095.

Likert, R. (1932). A technique for the measurement of attitudes. *Archives of Psychology*.

Livescault, J. (2022). Implementation: the key to successful innovation - Braineet.

MacKinnon, A. J., Duinker, P., and Walker, T. R. (2018). The Application of Science in Environmental Impact Assessment. *Routledge eBooks*.

Mahajan, B. (2023). What Is Self Healing Concrete: Advantages And Disadvantages.

Mancini, L. and Sala, S. (2018). Social impact assessment in the mining sector: Review and comparison of indicators frameworks. *Resources Policy*, 57:98–111.

Marinković, S. (2013). Life cycle assessment (LCA) aspects of concrete. *Elsevier eBooks*, pages 45–80.

Martin, P. Y. and Turner, B. A. (1986). Grounded Theory and Organizational Research. *The Journal of Applied Behavioral Science*, 22(2):141–157.

Mazzarol, T. (2020). 6 ways governments can encourage entrepreneurship.

McKinsey (2018). Seizing opportunity in todays construction technology ecosystem.

Meglin, R., Kytzia, S., and Habert, G. (2021). Regional circular economy of building materials: Environmental and economic assessment combining Material Flow Analysis, Input-Output Analyses, and Life Cycle Assessment. *Journal of Industrial Ecology*, 26(2):562–576.

Meyer, C. (1998). *Relentless Growth*. Simon and Schuster.

Miłkowski, B. (2022). How KanBo Enables Construction Companies to Foster Innovation?

Molloy, J. (2019). Five Steps to Implementing Innovation. *Harvard Business Publishing*.

Muralikrishna, I. V. and Manickam, V. (2017). Life Cycle Assessment. *Elsevier eBooks*, pages 57–75.

Niemeyer, S., Petts, J., and Hobson, K. (2005). Rapid Climate Change and Society: Assessing Responses and Thresholds. *Risk Analysis*, 25(6):1443–1456.

OECD (2014). The Cost of Air Pollution. *OECD eBooks*.

Ofori, G. (1990). *The Construction Industry.* Amsterdam University Press, Amsterdam, Netherlands.

Ozorhon, B., Abbott, C., and Aouad, G. (2014). Integration and Leadership as Enablers of Innovation in Construction: Case Study. *Journal of Management in Engineering*, 30(2):256–263.

Pal, M., Karaliūtė, V., and Malik, S. (2023). Exploring the Potential of Carbon Capture, Utilization, and Storage in Baltic Sea Region Countries: A Review of CCUS Patents from 2000 to 2022. *Processes*, 11(2):605.

Paredes, R. (2022). Innovations Shaping the Construction Industry.

Patil, R. (2021). Self Healing Concrete.

Pulidindi, K. and Bhalerao, S. (2021). Precast concrete market size by element.

Purvis, B., Mao, Y., and Robinson, D. (2018). Three pillars of sustainability: in search of conceptual origins. *Sustainability Science*, 14(3):681–695.

Ramsey, J. L. (2015). On Not Defining Sustainability. *Journal of Agricultural and Environmental Ethics*, 28(6):1075–1087.

Rangaiah, M. (2021). 3D Printing Technology: Advantages and Disadvantages — Analytics Steps.

Reichstein, T., Salter, A. J., and Gann, D. M. (2005). Last among equals: a comparison of innovation in construction, services and manufacturing in the UK. *Construction Management and Economics*, 23(6):631–644.

Rhode, E. (2021). Carbon Capture and Storage (CCS) Pros and Cons.

Rodgers, B. L. (2018). Climate change: The massive CO2 emitter you may not know about. -.

Rogers, P., Puryear, R., and Root, J. (2013). Infobesity: The enemy of good decisions.

Sandanayake, M., Bouras, Y., Haigh, R., and Vrcelj, Z. (2020). Current Sustainable Trends of Using Waste Materials in Concrete—A Decade Review. *Sustainability*, 12(22):9622.

School, S. C. S. (2022). Sustainability Strategy.

Seaden, G., Guolla, M., Doutriaux, J., and Nash, J. H. E. (2003). Strategic decisions and innovation in construction firms. *Construction Management and Economics*, 21(6):603–612.

Serdar, M., Bjegović, D., Štirmer, N., and Pečur, I. B. (2019). Alternative binders for concrete: opportunities and challenges. *Future trends in Civil Engineering.*

Serdyukov, P. (2017). Innovation in education: what works, what doesn't, and what to do about it? *Journal of research in innovative teaching & learning*, 10(1):4–33.

Shavinina, V, L. (2003). *The International Handbook on Innovation.* Pergamon, 1 edition.

Sivakrishna, A., Adesina, A., Awoyera, P., and Rajesh Kumar, K. (2020). Green concrete: A review of recent developments. *Materials Today: Proceedings*, 27:54–58.

Software, P. C. (2020). Exploring 8 Green Innovations that Transform Concrete.

Stephanie (2020). Communality: Definition, Examples - Statistics How To.

Straits Research, S. (2022). Precast Concrete Market Growth, Share, Forecast to 2030.

Strauss, A. L. and Corbin, J. M. (1994). Grounded theory methodology: An overview. *Strategies of Qualitative Inquiry.*

Subramanya, K., Kermanshachi, S., and Rouhanizadeh, B. (2020). Modular Construction vs. Traditional Construction: Advantages and Limitations: A Comparative Study. *Proceedings of the Creative Construction e-Conference 2020.*

Suhendro, B. (2014). Toward Green Concrete for Better Sustainable Environment. *Procedia Engineering*, 95:305–320.

Swamy, R. N. (2001). Holistic design: key to sustainability in concrete construction. *Proceedings of the Institution of Civil Engineers - Structures and Buildings*, 146(4):371–379.

Tangkar, M. and Arditi, D. (2004). INNOVATION IN THE CONSTRUCTION INDUSTRY.

Tanner, R. (2020). Ten Organizational Barriers that Limit Innovation.

Toor, M. (2022). How to design rating scale questions.

Union, E. (2016). Regulatory barriers for the circular economy.

Van Den Heede, P. and De Belie, N. (2012). Environmental impact and life cycle assessment (LCA) of traditional and 'green' concretes: Literature review and theoretical calculations. *Cement & Concrete Composites*, 34(4):431–442.

Vishwakarma, V. and Uthaman, S. (2020). Environmental impact of sustainable green concrete. *Elsevier eBooks*, pages 241–255.

Wang, B., Yan, L., Fu, Q., and Kasal, B. (2021). A Comprehensive Review on Recycled Aggregate and Recycled Aggregate Concrete. *Resources Conservation and Recycling*, 171:105565.

Watts, J. (2021). Resource extraction responsible for half world's carbon emissions. -.

Weil, M., Dombrowski, K., and Buchwald, A. (2009). Life-cycle analysis of geopolymers. *Elsevier eBooks*, pages 194–210.

Wiersum, K. F. (1995). 200 years of sustainability in forestry: Lessons from history. *Environmental Management*, 19(3):321–329.

Xichen, C., Chang-Richards, A., Pelosi, A., Jia, Y., Shen, X., Siddiqui, M. K., and Yang, N. (2021). Implementation of technologies in the construction industry: a systematic review. *Engineering, Construction and Architectural Management*, 29(8):3181–3209.

Young, C. (2021). What is variance in factor analysis.

Yılmaz, M. and Bakış, A. (2015). Sustainability in Construction Sector. *Procedia - Social and Behavioral Sciences*, 195:2253–2262.

Zhao, Y., Yu, M., Xiang, Y., Kong, F., and Li, L. (2020). A sustainability comparison between green concretes and traditional concrete using an emergy ternary diagram. *Journal of Cleaner Production*, 256:120421.

Appendix A

Online Survey

Sustainability in Construction: Implementation of Green Concrete Solutions

How to strategically implement Green Concrete solutions in construction projects by means of sustainable development of innovations towards practical applications? This is the main research question that this graduation project is striving to answer.

The purpose of this survey is to obtain an overview on the perception of Green Concrete/other innovative materials and it will only take maximum 5 minutes of your time (16 simple questions).

Thank you for participation! Your input is greatly appreciated!

Disclaimer: All the provided information will be strictly used for research purposes. No

1. What is your PMC?

2. On a scale from 1 to 10, how familiar are you with the concept of Green Concrete?

0	1	2	3	4	5	6	7	8	9	10

Not at all — Extremely familiar

3. How would your define Green Concrete with only 3 key words?

4. Do you think that Green Concrete is important for the construction industry?

- ◯ Yes
- ◯ No
- ◯ Maybe

5. How important would you say that Green Concrete is?

0	1	2	3	4	5	6	7	8	9	10

Not at all — Extremely important

6. How open would you say that the construction industry is in regards to new materials?

0	1	2	3	4	5	6	7	8	9	10

Not open at all — Extremely open

7. Do you consider that the industry is willing to adopt Green Concrete solutions?

0	1	2	3	4	5	6	7	8	9	10

Not at all likely — Extremely likely

8. Would you consider that Green Concrete is promoted sufficiently in current practices?

0	1	2	3	4	5	6	7	8	9	10

Not at all Very promoted

9. Did you have any opportunity to work with Green Concrete or other new innovative material?

- Yes
- No

10. Would you like to work on a project that involves Green Concrete or other innovative material?

- Yes
- No
- Maybe

11. With what type of Green Concrete or other innovative material did you work?

12. What were the main challenges when working with Green Concrete or other innovative material?

13. How would you prioritize the 3 given aspects of sustainability when it comes to Green Concrete? (top being the most important and bottom the least important)

- Environment
- Economy
- Society

14. According to literature, these are 10 most common barriers to innovation. On a scale from 1 to 5, how would you grade them by impact (1 least impact - 5 greatest impact)

	1	2	3	4	5
Fear	◯	◯	◯	◯	◯
Lack of leadership	◯	◯	◯	◯	◯
Short-term thinking	◯	◯	◯	◯	◯
Lack of resource/capacity	◯	◯	◯	◯	◯
Lack of collaboration	◯	◯	◯	◯	◯
No time	◯	◯	◯	◯	◯
Lack of focus	◯	◯	◯	◯	◯
Lots of ideas, no market delivery	◯	◯	◯	◯	◯
No clear process	◯	◯	◯	◯	◯
Lack of urgency	◯	◯	◯	◯	◯

15. How likely are you to recommend Green Concrete as a reliable construction solution?

0	1	2	3	4	5	6	7	8	9	10

Not at all likely — Extremely likely

16. What is your main concern regarding Green Concrete?

17. Would you be willing to possibly discuss further this topic in an interview?

- ◯ Yes
- ◯ No

18. What is your Witteveen+Bos name code?

Appendix B

Survey Results - Frequency Tables

Table B.1: Familiarity with GC - Frequency of scores

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not at all	4	4.7	4.7	4.7
	1	3	3.5	3.5	8.2
	2	15	17.6	17.6	25.9
	3	10	11.8	11.8	37.6
	4	6	7.1	7.1	44.7
	Neutral	13	15.3	15.3	60.0
	6	10	11.8	11.8	71.8
	7	11	12.9	12.9	84.7
	8	8	9.4	9.4	94.1
	9	5	5.9	5.9	100.0
	Total	85	100.0	100.0	

Table B.2: The relevance of GC

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	68	80.0	80.0	80.0
	No	1	1.2	1.2	81.2
	Maybe	16	18.8	18.8	100.0
	Total	85	100.0	100.0	

Table B.3: The Importance of GC

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	3	1	1.2	1.2	1.2
	4	1	1.2	1.2	2.4
	Neutral	5	5.9	5.9	8.2
	6	9	10.6	10.6	18.8
	7	14	16.5	16.5	35.3
	8	23	27.1	27.1	62.4
	9	17	20.0	20.0	82.4
	Extrimely	15	17.6	17.6	100.0
	Total	85	100.0	100.0	

Table B.4: Industry Openness to new materials

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1	1	1.2	1.2	1.2
	2	9	10.6	10.6	11.8
	3	15	17.6	17.6	29.4
	4	11	12.9	12.9	42.4
	Neutral	6	7.1	7.1	49.4
	6	24	28.2	28.2	77.6
	7	7	8.2	8.2	85.9
	8	9	10.6	10.6	96.5
	9	1	1.2	1.2	97.6
	Extrimely	2	2.4	2.4	100.0
	Total	85	100.0	100.0	

Table B.5: Industry Willingness to adopt GC

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	2	1	1.2	1.2	1.2
	3	2	2.4	2.4	3.5
	4	5	5.9	5.9	9.4
	Neutral	13	15.3	15.3	24.7
	6	23	27.1	27.1	51.8
	7	15	17.6	17.6	69.4
	8	22	25.9	25.9	95.3
	9	3	3.5	3.5	98.8
	Extremely	1	1.2	1.2	100.0
	Total	85	100.0	100.0	

Table B.6: Promotion Levels of GC in current practices

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not at all	2	2.4	2.4	2.4
	1	5	5.9	5.9	8.2
	2	12	14.1	14.1	22.4
	3	21	24.7	24.7	47.1
	4	17	20.0	20.0	67.1
	Neutral	12	14.1	14.1	81.2
	6	7	8.2	8.2	89.4
	7	2	2.4	2.4	91.8
	8	5	5.9	5.9	97.6
	9	1	1.2	1.2	98.8
	Extremely	1	1.2	1.2	100.0
	Total	85	100.0	100.0	

Table B.7: Likelihood to recommend GC

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not at all	1	1.2	1.2	1.2
	1	1	1.2	1.2	2.4
	2	2	2.4	2.4	4.7
	3	2	2.4	2.4	7.1
	4	7	8.2	8.2	15.3
	5	18	21.2	21.2	36.5
	6	14	16.5	16.5	52.9
	7	21	24.7	24.7	77.6
	8	15	17.6	17.6	95.3
	9	3	3.5	3.5	98.8
	Extremely Likely	1	1.2	1.2	100.0
	Total	85	100.0	100.0	

Appendix C

Survey - Frequency of Words

The numbers attributed to each word represents the frequency that word was mentioned in the answers.

What is Green Concrete in key-words:

- Reusable - 6
- Unknown - 5
- Greenwashing - 1
- Interesting - 1
- Future - 4
- Eco-friendly - 11
- Robust - 1
- CO2reduction - 14
- Carbonneutral - 8
- Innovation - 3
- Alternative - 5
- Cementreduction - 6
- Recyclable - 9
- Cementreplacement - 6
- Geopolymer - 9
- Residential - 1
- Concretereduction - 1
- Sustainable - 17
- Biobased - 4

- Better - 1
- Expensive - 2
- Lowenvironmentimpact - 1
- Waste - 5
- Circular - 5
- Durable - 4
- Broad - 1
- Undeveloped - 1
- Closedlifecycle - 1
- Energyneutral - 1
- Highquality - 1
- Affordable - 1
- Lesspollutant - 1
- Developing - 1
- Additives - 1
- Slag - 1
- Greenwash - 1
- Fibres - 1
- Weaker - 1
- 3D-printing - 1
- Moss - 1
- CO2 - 2
- Carboncapture - 2
- New - 1
- Longevity - 1
- Environment - 1
- Cementfree - 4
- Recycledaggregates - 1

Frequency of words in survey - Main Concerns:

- Permits - 2
- Regulations - 5
- Risks - 1
- Unknown material - 1
- Properties - 3
- Rules - 5
- Methods - 1
- Lack of calculations - 1
- Quality - 1
- Strength - 2
- Time - 2
- Money - 1
- Approval - 2
- Cost - 2
- Decommissioning - 1
- Opportunities - 1
- Standards - 6
- Norms - 2
- Knowledge - 2
- References - 1
- Guidelines - 2
- Conservatism - 1
- Fear - 1
- Client - 3
- Performance - 1
- Proof - 1
- Limited applications - 1
- Structural aspects - 1
- Legislation - 1

- Behaviour - 1
- Certifications - 1
- Lifespan - 1
- Experience - 1
- Codes - 1
- Responsibilities - 1
- Approvals - 1

Frequency of words in survey - Main Challenges:

- Price - 3
- Needs more validation - 1
- Willingness of the companies to make the change - 1
- Structural requirements - 2
- Long term durability - 2
- Lack of experience - 2
- Long term behaviour - 1
- Material properties - 1
- Availability - 3
- Lack of knowledge - 3
- Durability - 3
- Greenwashing - 1
- Lack of recommendations - 1
- Reliability - 2
- Safety - 2
- Behaviour - 1
- Mechanical properties - 1
- Strength - 2
- Environmental impact - 1
- Knowledge - 2

- Sharing the knowledge - 1
- Risks - 2
- Investment - 2
- Familiarity - 1
- Development - 1
- Standards - 2
- Regulations - 3
- Acceptance - 1
- Proof - 3
- Slow progress - 1
- Speed of the transition - 1
- Carbon footprint - 1
- Applicability - 1
- Promotion - 1
- Experience - 2
- Lack of reference - 1
- Norms - 1
- Supply chain - 3
- Unfamiliarity - 1
- Requirements - 1
- Lifetime expectation - 2
- Time - 1
- Performance - 1

Appendix D

Factor Analysis - Correlation Matrix

		Familiarity with GC	Relevance of GC	Importance of GC	Prior experience with GC/other material	Interest in GC	Recommending GC
Correlation	Familiarity with GC	1.000	-.431	.342	-.588	-.442	.584
	Relevance of GC	-.431	1.000	-.471	.214	.420	-.477
	Importance of GC	.342	-.471	1.000	-.228	-.337	.348
	Prior experience with GC/other material	-.588	.214	-.228	1.000	.294	-.485
	Interest in GC	-.442	.420	-.337	.294	1.000	-.427
	Recommending GC	.584	-.477	.348	-.485	-.427	1.000
	Industry Openness	.292	-.222	.089	-.161	-.126	.254
	Industry Acceptance	.217	-.269	.261	-.169	-.223	.298
	Industry Promotion	.283	-.187	.046	-.098	-.072	.243
	Fear	.056	.142	-.176	-.046	-.073	.042
	Lack Of Leadership	.339	-.046	.161	-.143	-.259	.239
	Short-term Thinking	-.027	-.092	.159	.101	-.122	-.001
	Lack of Resource/Capacity	-.095	-.009	-.005	.025	.224	-.092
	Lack of Collaboration	-.016	-.143	-.003	.054	.017	.047
	No Time	.205	-.134	.158	-.144	-.004	.010
	Lack of Focus	.270	-.128	.169	-.164	-.005	.061
	Lots of Ideas, No Market Delivery	.004	.011	-.059	-.143	-.014	-.102
	No Clear Process	.172	-.138	-.048	.079	-.061	.120
	Lack of Urgency	-.051	-.001	.240	-.034	.131	-.057

a. Determinant = ,008

Figure D.1: Correlation Matrix - part 1

Correlation Matrix[a]

Industry Openness	Industry Acceptance	Industry Promotion	Fear	Lack Of Leadership	Short-term Thinking	Lack of Resource/Capacity	Lack of Collaboration	No Time
.292	.217	.283	.056	.339	-.027	-.095	-.016	.205
-.222	-.269	-.187	.142	-.046	-.092	-.009	-.143	-.134
.089	.261	.046	-.176	.161	.159	-.005	-.003	.158
-.161	-.169	-.098	-.046	-.143	.101	.025	.054	-.144
-.126	-.223	-.072	-.073	-.259	-.122	.224	.017	-.004
.254	.298	.243	.042	.239	-.001	-.092	.047	.010
1.000	.321	.418	-.070	.004	-.049	.005	.006	.138
.321	1.000	.232	-.060	.122	-.057	-.011	.024	.126
.418	.232	1.000	.087	.042	-.160	.021	.014	.225
-.070	-.060	.087	1.000	.097	-.124	-.044	-.008	-.038
.004	.122	.042	.097	1.000	.232	-.126	.082	-.145
-.049	-.057	-.160	-.124	.232	1.000	-.051	.120	.066
.005	-.011	.021	-.044	-.126	-.051	1.000	.178	.268
.006	.024	.014	-.008	.082	.120	.178	1.000	.200
.138	.126	.225	-.038	-.145	.066	.268	.200	1.000
.145	.139	.187	-.095	.183	.139	.130	.183	.267
.070	-.172	.154	.020	-.017	-.103	.023	.050	.006
.140	.093	.228	.114	.009	-.202	.122	.202	.168
-.068	-.092	-.219	-.057	.146	.181	.082	.092	-.105

Figure D.2: Correlation Matrix - part 2

No Time	Lack of Focus	Lots of Ideas, No Market Delivery	No Clear Process	Lack of Urgency
.205	.270	.004	.172	-.051
-.134	-.128	.011	-.138	-.001
.158	.169	-.059	-.048	.240
-.144	-.164	-.143	.079	-.034
-.004	-.005	-.014	-.061	.131
.010	.061	-.102	.120	-.057
.138	.145	.070	.140	-.068
.126	.139	-.172	.093	-.092
.225	.187	.154	.228	-.219
-.038	-.095	.020	.114	-.057
-.145	.183	-.017	.009	.146
.066	.139	-.103	-.202	.181
.268	.130	.023	.122	.082
.200	.183	.050	.202	.092
1.000	.267	.006	.168	-.105
.267	1.000	.263	.288	.330
.006	.263	1.000	.172	.101
.168	.288	.172	1.000	.108
-.105	.330	.101	.108	1.000

Figure D.3: Correlation Matrix - part 3

Appendix E

Interview Invitation

Sustainability in Construction: Implementation of Green Concrete Solutions in Construction Projects
INTERVIEW QUESTIONS

You are being invited to participate in a research study titled Sustainability in Construction: Implementation of Green Concrete Solutions in Construction Projects. This study is being done by Alexandru Zaharia from the TU Delft in collaboration with Witteveen+Bos. The purpose of this research is to gain insights into real-world practices in regard to the implementation of green concrete solutions. The interview will take about 60 minutes, the session is recorded and transcripts will be extracted for research purposes only. All the data used for this research will be non-identifiable and non-traceable to the interviewee.

Your participation in this study is entirely voluntary, and you can withdraw at any time. You are free to omit any questions.

Thank you!

Corresponding researcher,
Alexandru Zaharia
alexandru.zaharia@witteveenbos.com

1. What is your profession?
   (a) Where do you work?
   (b) What is your job title?
   (c) How many years of experience do you have?
2. How do you see sustainability in construction and what do you think can be done to achieve it?
3. How would you describe innovation in the construction sector, generally speaking?
4. Who do you think that has the most power to implement innovations from all the possible stakeholders involved in the construction industry?
   (a) If you would be in that power position what would be one thing that you would do to help innovations become practical applications?

5. How would you describe Green Concrete with your own words?
6. What are your thoughts on the state of green concrete in the industry as of today?
7. Is Green Concrete of any importance to the current construction market?
   (a) Why?
8. Do you believe green concrete should always be used in new buildings or are there occasions where it is not an appropriate choice?
9. What are some challenges that can occur by using green concrete in construction?
   (a) Examples?
   (b) How did you experience the challenges in your project/organisation?
   (c) Any similar instances?
   (d) Some other challenges?
10. What are some of the most innovative and exciting materials you have worked with in your career?
    (a) What kind of material?
    (b) What kind of project?
    (c) What did you like about that new material?
    (d) What did you not like about that new material?
    (e) What were the challenges you faced?
    (f) How were those issues solved?
    (g) Where do you think those issues came from?