Stimulating the Adoption of Green Concrete in the Project Level:

A Demand Side Perspective

Construction Management and Engineering

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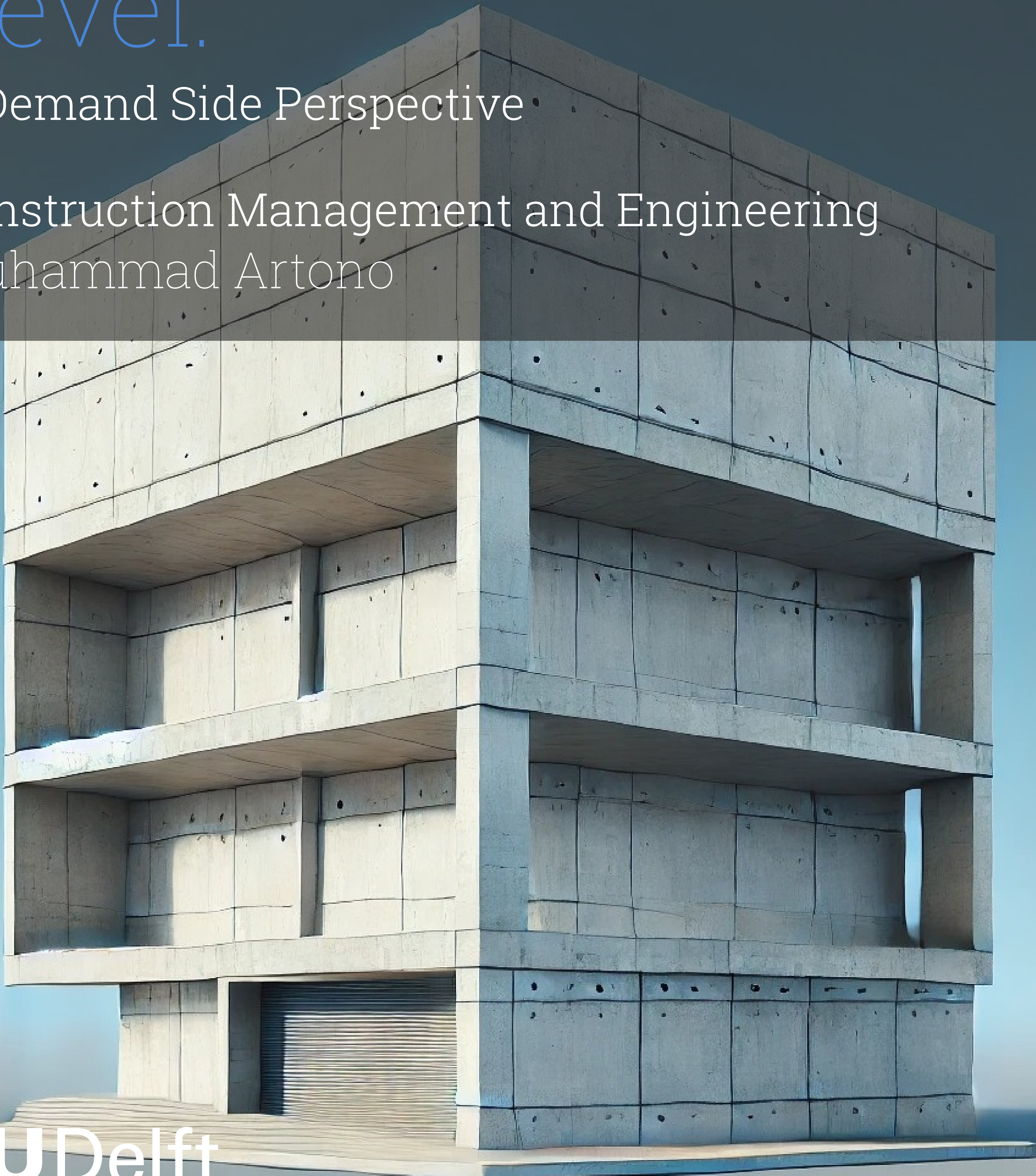

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by

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Muhammad Artono
Delft, August 2024

Preface

In the nature of technological transitions, the process is usually represented by an exponential curve, where progress is slow and incremental over a long period until it reaches the acceleration point. Once it reaches this point, the transition speed increases exponentially. This research aims to fill the story between the starting line and that acceleration point. Following my main program of study in Construction Management and Engineering, this research intends to facilitate the transition of one of the most important and conservative components in the built environment: cement and concrete. This thesis, titled ”Stimulating the Adoption of Green Concrete at the Project Level: A Demand-Side Perspective,” seeks to provide a new paradigm for concrete, a material that has been established for over a century, to meet new challenges in carbon emission reduction and circularity utilising the role of the purchaser. The challenge of transitioning this industry to meet the 2030 and 2050 emission targets presents unique difficulties compared to other sectors.

Using the analogy of maps and road users, the purchaser, as the driver, should not only be aware of the immediate road and the next one or two intersections but also understand the entire journey, including the grand destination and all potential barriers and opportunities along the way. In the first section of this empirical study, the research provides insights for concrete purchasers regarding the current status of the green concrete transition in the country. I hope these insights will increase awareness among demand-side organisations about their position in the transition process by offering a comprehensive overview.

Just like driving a car, understanding micro-level details, such as vehicle characteristics and local traffic conditions, can help ensure a successful trip. At the practical level, this research highlights the real conflicts and differences between high-level goals and practical realities. It is fascinating to understand how practitioners interpret and perceive the high-level goal of transitioning concrete and the compatibility of their interests. Gaining insights into such combinations is crucial not only for practising green concrete projects but also for other sustainable innovations and challenges in construction projects.

By providing this research with a two-level empirical study, I hope to assist demand-side organisations in selecting suitable green concrete solutions, preparing effective implementation strategies, and ultimately contributing optimally to the transition process at the macro level.

Muhammad Artono
Delft, August 2024

Executive Summary

Introduction and Problem Statement

The Dutch Climate Act (2019) aims to reduce greenhouse gas (GHG) emissions by 49% by 2030 and 95% by 2050. The built environment, contributing 15% of the Netherlands' CO2 emissions, heavily relies on concrete, which significantly contributes to CO2 emissions, accounting for up to 8% of global emissions. Emissions occur throughout the lifecycle of concrete, from material extraction to demolition, with direct CO2 emissions mainly stemming from cement production.

Recent research focuses on developing environmentally friendly alternatives to conventional cement and concrete, such as Supplementary Cementitious Materials (SCMs), Alkali-Activated Binders, and recycled aggregates. The transition towards sustainable concrete is essential in the Netherlands. The demand-side, particularly purchasers, holds significant potential to influence this transition. By setting environmental standards and prioritising green concrete in their projects, these organisations can leverage their purchasing power to shape market trends. However, the adoption of green concrete among purchasers in the Netherlands remains limited due to various barriers, including systemic lock-ins, vested interests, risk-averse behavior, and a lack of knowledge.

This study investigates how demand-side organisations can accelerate the adoption of green concrete at the project level, focusing on developing strategies to promote green concrete throughout all project stages. The main research question is:

How can demand-side organisations stimulate the adoption of green concrete at the project level?

Methodologies

Four sequential steps were conducted to answer this question. First, understanding green concrete's definition, barriers, and enablers through a literature study provided a foundational background for the research. The next step involved understanding the macro-level green transition process in the Netherlands to provide strategic insights into demand-side expectations for the overall transition, as explained by the Multi-level Perspective (MLP) Framework. This first empirical study involved twelve respondents through semi-structured interviews representing key players in the Dutch concrete sectors. In the second empirical study, multiple case studies were performed, followed by semi-structured interviews with fourteen respondents to develop practical strategies, utilizing one construction project with conventional concrete (SCM) and two projects with green concrete (geopolymer and recycled aggregate) as innovative cases. Cross-case analysis identified similarities and differences, providing insights into managing green concrete projects. Finally, a conceptual framework was developed, combining strategic and practical levels to guide demand-side organisations in optimizing their contribution to the transition process.

Findings

At the macro level, the European Union's Emission Trading System (EU ETS) plays a significant role in motivating emission reductions in cement manufacturers by taxing carbon emissions. In the Netherlands, green concrete development is advanced due to the extensive use of SCM CEM III, which is supported by high-quality and quantity slag from local steel producers. Despite these advancements, the industry would face challenges from potential slag shortages due to shifts in the steel industry towards Direct Reduced Iron (DRI) technology, prompting the need for alternative SCMs. SCM CEM III is perceived as the dominant actor at the regime level, successfully integrated with socio-technical aspects. Potential new entrants may hybridise with incumbents, such as calcined clays, volcanic ashes, and carbon capture technologies, while geopolymer concrete is seen as an independent niche-level innovation. Contributions from purchasers for the transition include promoting the "cement with purpose" practice, demonstrating pilot projects for radical innovation, creating aggregate demand for near-mature innovations, standardising concrete requests, and developing new materials to replace slag. Achieving the 2030 and 2050 targets will require multiple solutions instead of a single dominant regime.

At the project level, the absence of operational and tangible sustainability targets inhibits the adoption of green concrete. Most innovations in the innovative cases depend on the personal interest of the project team. In conservative cases, barriers include reluctance from the asset team, conflicts of interest with other priorities such as safety, and high Technology Readiness Level (TRL) acceptance. In innovative cases, the capability of the engineering team is a key enabler for adopting green concrete. Other enablers include recognition of pilot project status and willingness to accept higher risks.

During design and planning, partnerships with expert organisations and conservative approaches in design and code are needed. Prescriptive and detailed specifications steer the market toward specific innovations in procurement. Warranty exemptions for concrete scope can increase contractors' willingness to join the project, with extensive testing compensating for the absence of warranties and codes. Generally, a higher client's willingness to accept risk is crucial for the success of sustainable innovations like green concrete. Conversely, conservative cases depend on De milieukostenindicator (MKI)-Environmental Cost Indicator and functional specifications to encourage sustainable innovation, making it more suitable for innovations with higher TRL.

Strategies (Framework) Synthesis

Combining strategic insights at the national level with practical project-level strategies, an integrative framework (Figure 1 and 2), Green Concrete Adoption Strategy for Purchasers (GCAS-4P), adapted from Loorbach (2010), is developed for demand-side organisations to optimise their contribution to the green concrete transition process. The higher-level framework is intended for strategic decision-making, considering stakeholder behaviour, future material availability, bulk industry nature, new material development, and the "cement with purpose" concept. The middle layer addresses managerial and practical aspects, helping organisations understand their response to innovation, including risk-aversion or frontrunner status, in-house engineering capability, and key performance indicators (KPIs) of sustainable innovation in construction. The most practical strategies are developed for project phases from initiation to post-construction, considering client risk acceptance, pilot project recognition, early asset team involvement, budget consolidation, low-risk applications, specification's strategy, pre-market consultation, warranty adjustment, comprehensive testing, and post-construction monitoring.

Discussion and Recommendations

The Multi-Level Perspective (MLP) framework explains the hierarchical dynamics driving the green concrete transition in the Netherlands, highlighting interactions between niche innovations like geopolymer, calcined clays, and regime actors such as SCM CEM cement manufacturers. It underscores pressures from higher levels, including the EU ETS and changes in the steel industry, using mechanisms like breakout and hybridization to anticipate future developments. However, the MLP framework inadequately captures top-down relationships between the regime and niche levels, the role of multi-actor incumbents, and interactions with other industries, limiting its comprehensiveness.

The research faces limitations in comprehensiveness and applicability. Focusing on the Netherlands limits generalisability, given the small contribution to global cement usage. Exploring transitions at a broader EU or Benelux level could provide more insights. The case study is confined to regional and municipal organisations, excluding national public clients and private sectors. The study presumes decision-making lies with client organisations, overlooking the influence of intermediate actors like engineering consulting companies.

Future research should include the supplier's perspective, encompassing more responses from cement manufacturers. Understanding competition between front-end carbon reduction methods and Carbon Capture and Utilisation Storage (CCUS) is crucial, as advancements in one area could impact the other. Examining case studies endorsed by incumbent cement manufacturers could provide different strategies. Investigating the role of purchasers in promoting practices that reduce concrete usage is essential for a comprehensive transition strategy.

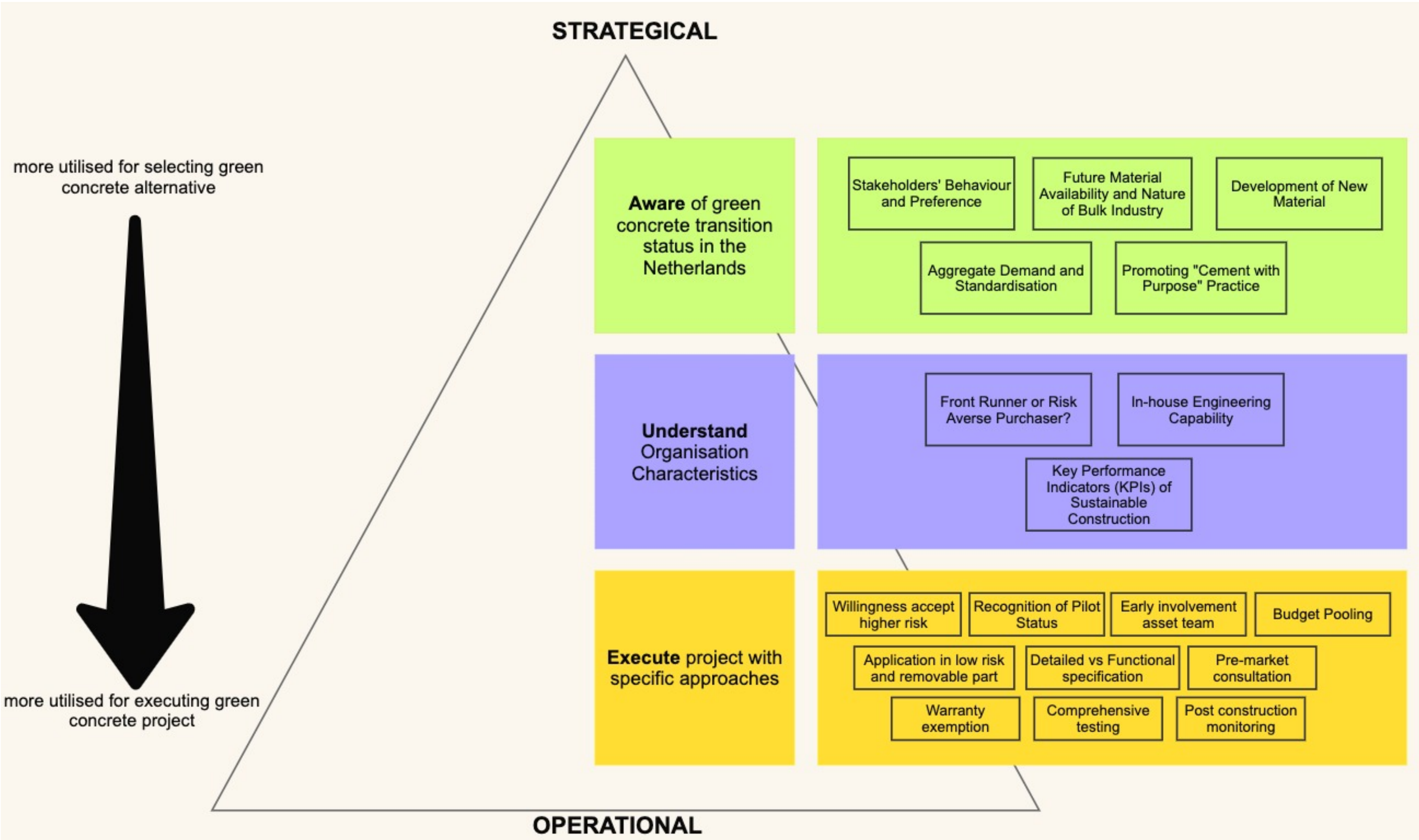

Figure 1: Green Concrete Adoption Strategy for Purchasers (GCAS-4P) Framework

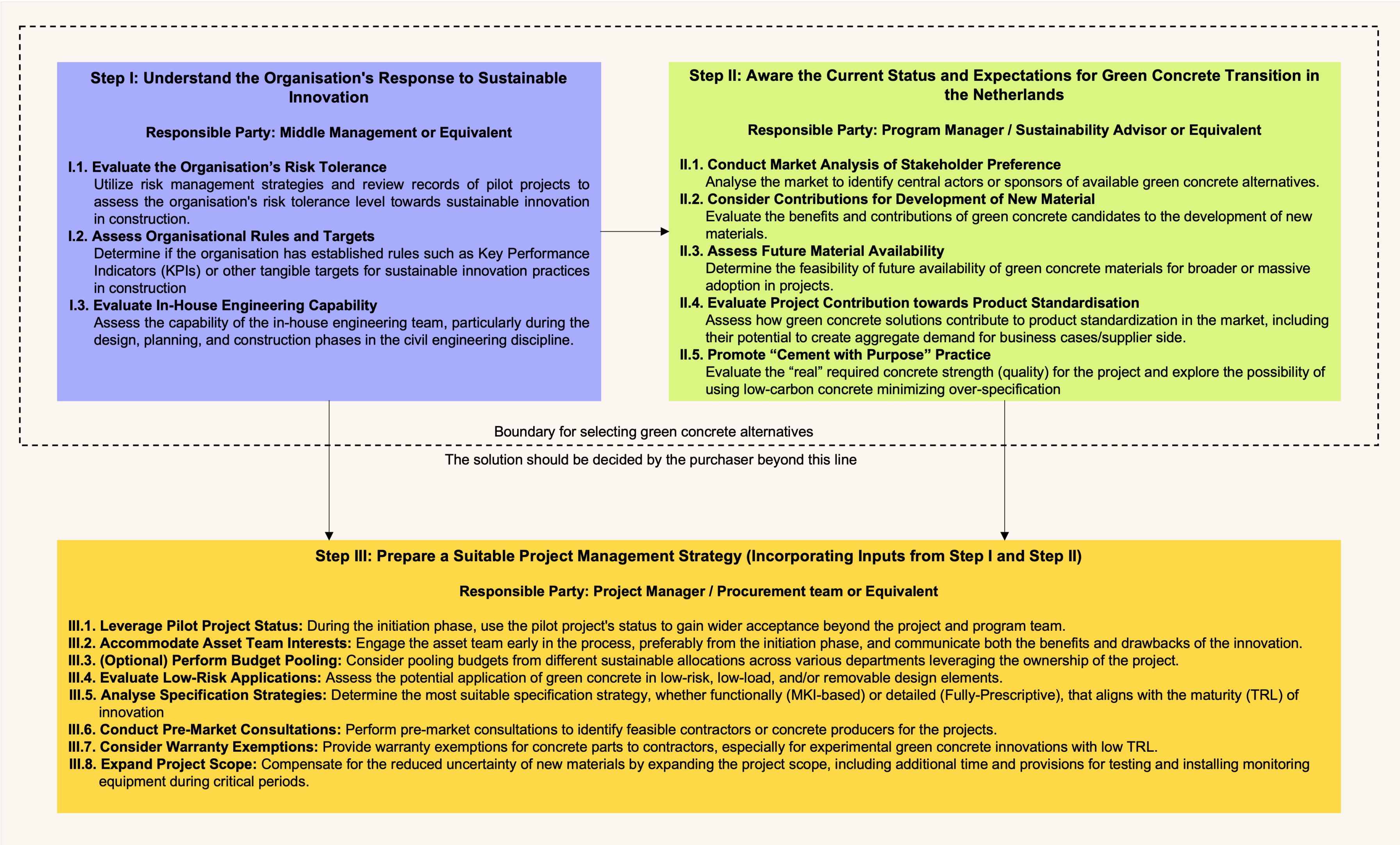

Figure 2: Guidance for GCAS-4P Framework Implementation

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Nomenclature

Abbreviations

Abbreviation	Definition
CBAM	Carbon Border Adjustment Mechanism
CCUS	Carbon Capture and Utilisation Storage
DRI	Direct Reduced Iron
EU ETS	European Union's Emission Trading System
GCAS-4P	Green Concrete Adoption Strategy for Purchasers
GHG	Greenhouse gas
KPIs	Key Performance Indicators
MKI	De milieukostenindicator (Environmental Cost Indicator)
MLP	Multi-level Perspective
MPG	MilieuPrestatie Gebouwen (Building Index Performance)
OPC	Ordinary Portland Cement
PPI	Public Procurement for Innovation
PRiSM	Projects integrating Sustainable Methods
SCMs	Supplementary Cementitious Materials
SMP	Sustainability management plan
TRL	Technological Readiness Level

1 Introduction

1.1. Background

According to the Dutch Climate Act of May 28, 2019, the Dutch government aims to reduce the Netherlands' greenhouse gas (GHG) emissions by 49% by 2030, compared to 1990 levels, and achieve a 95% reduction by 2050 (Ministerie van Economische Zaken, 2019). Furthermore, fifteen per cent of the CO2 emissions in the Netherlands occur in the built environment (CBS, 2018). One of the important components in the built environment is concrete (Gebremariam et al., 2020). This material is used in various structures, including buildings, bridges, roads, and dams, due to their strength and durability. However, concrete produces emissions of CO2 GHG amounting to about 2% to 8% of global power consumption due to the cement manufacturing process (Benhelal et al., 2013).

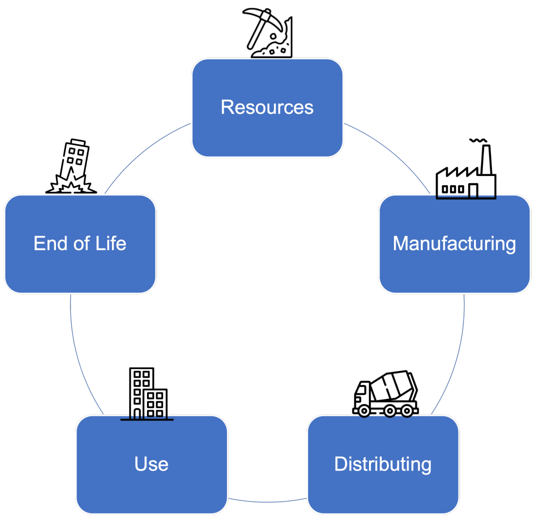

Figure 1.1: Emission throughout the life cycle of the product (Own figure)

Concrete emission occurs throughout the product's entire life cycle, starting from raw material extraction until the demolition (Huntzinger & Eatmon, 2009). In general, direct CO2 emissions related to concrete largely come from cement production, while the largest indirect emissions stem from transporting concrete to the end user (Teo et al., 2010).

1. Material extraction and clinker: During this process, limestone, clay, shale, and marl are extracted and processed through drilling, crushing, and the kiln process to produce an intermediate material for cement known as clinker. The kiln process contributes to high emissions, accounting for approximately 60%-65% of all cement manufacturing processes (Ali et al., 2011). Additional CO2 emissions result from the fuels used to heat the kiln.

2. Production of binder (Cement): Once clinker is produced, it is mixed with gypsum and clinker substitutes and then ground to the correct fineness to create cement (Ali et al., 2011). Cement in concrete is a primary binding ingredient holding together the other concrete components, such as aggregates and water. While this stage emits less CO2, the electricity used for grinding and mixing can still be optimised.
3. Transport contributes to emissions in concrete production. This includes transport within the quarry and cement plant, transporting raw materials and fuels to a cement plant, and transporting cement products to end consumers (Teo et al., 2010).
4. Concrete production and construction: Concrete is manufactured by mixing cement with water, aggregates, and small quantities of chemical admixtures to improve properties and meet specific requirements.
5. End of service life and demolition: During this stage, a certain amount of CO2 emissions is generated by transporting demolition equipment and waste over long distances to disposal sites (Ali et al., 2011).

1.2. Problem Description

Many researchers, companies, and organisations have recently investigated innovative alternatives to traditional cement and concrete, aiming for environmentally friendly solutions. These alternatives, such as Supplementary Cementitious Materials (SCM), Alkali-Activated Binders, Alternative Cements, and the use of waste materials as aggregate in concrete, have been introduced (Sivakrishna et al., 2020).

Table 1.1: Green Concrete Alternatives Associated with CO2 Reduction in the Concrete Life Cycle

Green Concrete Alternatives	Resources Extraction (Cement)	Manufacturing (Cement)	Transport	Concrete Production	Use	End of life
Supplementary cementitious materials (SCMs)	(x) Industrial waste	(x) Reduce 10-50% volume				
Alkali Activated Binders Cements	(x) Alumino-silicate	(x) Replace cement totally				
Alternative Cements (CA & CSA)	(x) Less limestone	(x) Lower temperature				
Waste material as aggregate				(x) Plastic, slag, ceramic		

SCM are alternatives designed to partially replace Ordinary Portland cement (OPC) as a concrete binder. They primarily consist of waste and by-products from other industries, offering an effective means of managing such waste by incorporating it into concrete (Sivakrishna et al., 2020). Examples of SCM include silica fume, rice husk, fly ash, and slag. Alkali-activated binders also stand out as promising green alternatives to OPC. These binders replace OPC entirely with aluminosilicate precursors (Sivakrishna et al., 2020).

Their use results in lower carbon dioxide emissions during production compared to OPC (Liew et al., 2017). Concrete production requires a substantial amount of aggregates, and natural sources may not adequately meet the increasing demand (Liew et al., 2017). Hence, it becomes crucial to incorporate materials from alternative sources to supplement the supply from natural sources.

Despite the various innovations in green concrete, its implementation remains at a niche level and requires acceleration to achieve widespread adoption and transform the concrete industry (Wesseling & Van der Vooren, 2017). Moreover, several barriers to green concrete transition in the Netherlands have been identified, including systemic lock-ins on the demand side, vested interests among firms and industry associations, and a need for knowledge of purchaser organisation (Wesseling & Van der Vooren, 2017).

On the demand side, the lock-in problem shows how procurers of concrete are risk-averse, conservative, and lack knowledge of green concrete products. This is a systemic problem because it results in negative green concrete expectations, guiding the search instead to safe, conventional concrete (Wesseling & Van der Vooren, 2017). This behaviour has been institutionalised in the routinised procurement of the highest quality concrete that complies with norm and certification committees. In contrast, on the supply side, the vested interests of established firms differ along the supply chain. Established firms frequently find green concrete less profitable than their existing business case. Instead, their vested interests incentivise them to engage in strategic influence and induce systemic problems that inhibit the development of these green concrete alternatives (Dewald & Achternbosch, 2016).

Demand's Side Organisation

Demand-side organisation refers to the parties and collaborations of entities that utilise or specify the use of concrete within construction projects, such as municipalities, provinces, private companies, national public clients, concrete purchaser groups, etc. The demand side of the concrete is usually overlooked in terms of transition or innovation, such as in the green concrete theme (Edler & Georghiou, 2007). Unlike the supply side and policymakers, the demand's organisation or purchaser is more segregated (Schiele, 2010). Demand-side organisations of concrete, such as private companies, infrastructure owners, real estate firms, and engineering and construction companies, are widely dispersed across various institutions and scales. This diversity makes it challenging to form firm associations and develop collaborative agreements that involve these organisations due to their high level of segmentation (Schiele, 2010).

Nevertheless, the demand side plays a crucial role by setting environmental standards and creating significant demand for green concrete through project prioritization (Edquist & Zabala-Iturriagagoitia, 2012). This, in turn, influences suppliers and manufacturers to focus on green concrete production. For instance, during tender processes, users can specify using high-quality recycled concrete in their building projects. Moreover, as demand increases, it can lead to economies of scale in the production of green concrete, thereby reducing costs and making it more competitive with traditional concrete. Therefore, there needs to be a more specific strategy for implementing green concrete adoption at the demand-side organisation.

Significance of Project level

Within an organisation, the decision-making process during purchasing involves various levels, such as projects and program levels (Too & Weaver, 2014). However, at the project level, companies implement the products they intend to purchase (Kostopoulos et al., 2019). The business processes in a project-level setting include design and specification development, procurement, contracting and awarding, and the monitoring and controlling process (White & Fortune, 2002). It is vital to foster the adoption of green concrete at the ground level of demand-side organisations, where measurable steps can be achieved at the operational level and in a short time horizon.

Moreover, project-level initiatives can significantly increase innovation adoption by acting as direct applications and demonstrating their feasibility and benefits (Erik Eriksson, 2010). For example, when projects successfully incorporate green concrete, they provide tangible examples of its practicality and performance advantages. This can inspire confidence in other stakeholders, leading to wider acceptance and use. Moreover, successful projects can set benchmarks and standards for future construction, influencing industry norms and encouraging the shift towards more sustainable practices (Erik Eriksson, 2010). Therefore, it is necessary to provide tailored approaches for encouraging green concrete transition at the project level of demand-side organisations due to their significant influence on dictating the market.

1.3. Research Objectives

This study explores how demand-side organisations can accelerate green concrete innovation at the project level. The approach might be utilised by purchasing organisations to boost the use of green concrete at every stage of the project management process, including initiation, design, procurement, monitoring, and controlling. The strategy will be customised to suit the unique characteristics of each business process at the project level, aiming to encourage stakeholders to adopt green concrete more widely in their projects. In addition, the strategy is also designed to align with the company's vision and mission at the operational level, particularly for organisations already committed to circular and sustainable construction practices. Finally, the outcomes of this research are prepared to significantly contribute to the shift towards green concrete transition driven by the demand side of the market.

1.4. Research Question

Main Question :

How can demand-side side organisations stimulate the adoption of green concrete at the project level?

Sub-research Question :

1. What is green concrete, and what challenges and opportunities does it present in the built environment?
2. How is the transition to green concrete in the Netherlands described by the Multi-level Perspective (MLP) Framework?
3. What enablers and barriers do demand-side organisations face when considering the adoption of green concrete at the project level?
4. What strategies can demand-side side organisations develop to increase the adoption of green concrete at the project level?

1.5. Research Design

1st Sub-research Question

The first sub-research question will further recognise the state-of-the-art and relevant definition of green concrete solutions. A traditional literature review is necessary to identify the definition, barriers, and enablers of green concrete. This method addresses this sub-research question because it provides a broad understanding of green concrete that has already been explored in academia. Additionally, given that this sub-research question aims to establish a foundational research background, a literature review is the most appropriate approach.

A collection of papers will be chosen based on their relevancy by collecting information from relevant academic papers and scientific databases such as Google Scholar, Scopus, TU Delft Repository, and CBS. Green concrete, green cement, alternative cement, SCM, recycled aggregate, life cycle, sustainability, and circularity are the keywords used to filter specific topics. Combining these keywords helps to get more related sources, especially by adding the 'interdisciplinary' keywords that refer to multiple fields of studies and research.

Figure 1.2: Flow of 1st Research Question

2nd Sub-research Question

The second sub-research question will elaborate on the current status of the green concrete transition process in the Netherlands. The data collection will start with preliminary information and will be followed by a semi-structured interview with various actors in the Dutch concrete sector. The semi-structured interview method is chosen as it is well-suited for an exploratory approach to understanding the current transition in the Netherlands. Additionally, this method helps to obtain more accurate responses from experts within specific boundaries (country).

In-depth, semi-structured interviews with a number of experts (10-15) are required to explore the overall status of green concrete transition at the macro level within the Netherlands. Then, the result will be explained using a technological transition framework, which is a multi-level perspective (MLP) (Geels, 2002).

Figure 1.3: Flow of 2nd Research Question

3rd Sub-research Question

The third sub-research question will elaborate on the current barriers and enablers for the adoption of green concrete at the project level of the demand side organisation. The data collection will start with multiple case studies in green concrete projects of several client organisations, such as municipalities and provincial governments. multiple case studies with different characteristic types will be conducted. The case study method is more suitable for achieving generalisation as it provides practical examples and lessons learned from actual projects. This approach can be valuable for other demand-side organisations implementing similar strategies.

The case study selection will focus on purchasing organisations that have already implemented or are planning to use green concrete in their portfolio. Instead of random sampling, purposed sampling will be employed for more accurate generalisation validation (Eisenhardt, 1989). In-depth interviews with a number of parties (3-6 persons per case) are required to explore the current level of adoption of green concrete in the project.

Figure 1.4: Flow of 3rd Research Question

4th Sub-research Question

To answer the last sub-research question about strategies for increasing the adoption of green concrete at the project level, the data gathered from the previous sub-research question will be utilised in one cross-level analysis method. The conceptual, strategic framework for demand-side organisations will be synthesized by integrating findings from both macro and micro levels. A multi-level analysis will be conducted to examine the similarities and differences between these levels. This integrative framework is well-suited to address the sub-research question as it captures the overall findings and illustrates the relationships between the strategies.

Figure 1.5: Flow of 4th Research Question

In conclusion, the flow of research information, aligned with the subsidiary research questions, is depicted in the subsequent workflow diagram.

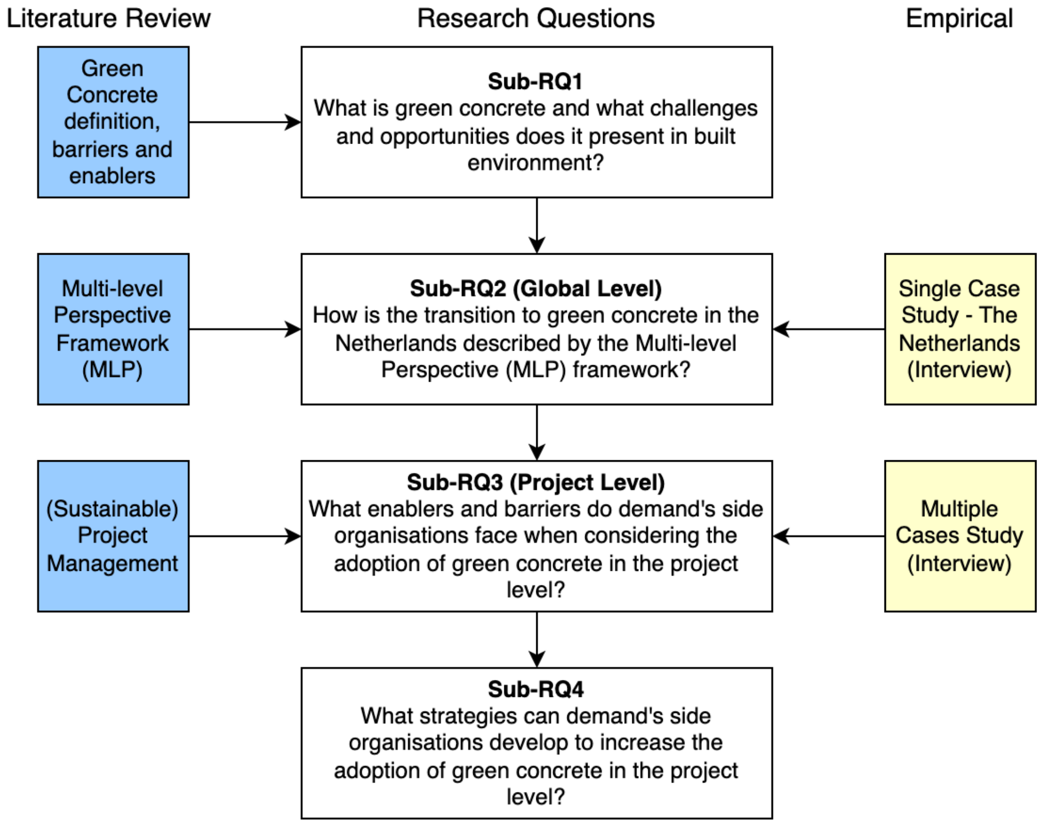

Figure 1.6: Schematic flow of research question

2

Literature Review

2.1. Green Concrete

Green concrete is generally identified as an eco-friendly building material developed to reduce the environmental impact compared to concrete with OPC. Technically, green concrete is characterised by the incorporation of recycled materials within its mix or through a production process that reduces carbon footprints (Liew et al., 2017). Several principles of green concrete were defined by (Suhendro, 2014), especially in the production process, such as lowering CO2 emissions, decreasing energy or fossil fuel reliance during concrete's binder (cement) production, reducing harmful substances, replacing concrete's binder (cement), and utilising recycled concrete and water in the concrete mix.

Moreover, the green concrete philosophy extends to the design and planning process. Strategies, like 3D printing of concrete (Bhattacherjee et al., 2021) and designing for disassembly (Salama, 2017), help minimise concrete use. In addition, enhancements like carbon capture and utilisation (CCUS) technology applied in end pipe of cement production are also acknowledged as green concrete (Izumi et al., 2021).

2.1.1. Green Concrete Development

Concrete's Binder (cement) substitution

The substitution of OPC in concrete represents a main strategy for developing green concrete solutions, as cement is responsible for a significant portion of the CO2 emissions due to the energy-intensive production process involving limestone calcination. Almost 5–7% of global CO2 emissions are caused by cement plants, while 900 kg CO2 is emitted to the atmosphere to produce one ton of OPC (Benhelal et al., 2013).

Binder substitution in green concrete involves using alternative materials such as fly ash, slag, silica fume, ground granulated blast furnace slag, calcined clays, and natural pozzolans (Juenger & Siddique, 2015). These practices are recognised as supplementary cementitious materials (SCM), commonly blended with clinker to make OPC or used as a replacement for a portion of OPC in concrete (Juenger & Siddique, 2015). For instance, research showed that utilisation of fly ash as substitution material could achieve a maximum of 60% by mass of cement (Hemalatha & Ramaswamy, 2017).

Slag, another by-product from steel production, when used as a binder replacement, contributes to the increased durability of concrete and its resistance to sulfate attack, making it particularly suitable for marine and road constructions (Gencel et al., 2021). Silica fume, a by-product of silicon and ferrosilicon alloy production, is noted for its ability to enhance both the mechanical properties and durability of concrete, especially in industrial applications where high strength is required (Golewski, 2021).

Geopolymer binders are typically synthesized from materials such as fly ash and slag activated by alkaline solutions. This solution is a promising alternative as it can be used as a total replacement of OPC (Almutairi et al., 2021). Moreover, this approach not only reduces the carbon footprint by up to 80% but also improves fire resistance and reduces toxicity (Marinković et al., 2017). Alkali-activated materials similarly present an eco-friendly alternative, delivering concrete with comparable or superior mechanical properties and durability (Turk et al., 2015).

Table 2.1: Summary of Green Concrete Solution

Approaches	Products	Emission Reduction in Concrete Life Cycle
Binder (cement) Substitution	SCM	Material extraction, cement manufacturing
	Geopolymer	Material extraction, cement manufacturing
	Alternative cement	Material extraction, cement manufacturing
Aggregate Substitution	Recycled aggregate	Material extraction, concrete production
Technological Innovation	CCUS	Cement manufacturing
Design and Construction	Design for disassembly	Concrete production
	Modular	Concrete production
	3D Printing	Concrete production

Aggregate Substitution

Research has shown that certain types of waste materials, when processed correctly, can replace natural aggregates without significantly compromising the structural integrity of the concrete. For instance, Using waste concrete as recycled aggregate could save about 60% of limestone resources and reduce CO2 emissions by about 15%–20% (Guo et al., 2018). Moreover, the use of seashell aggregates, which are by-products of the seafood industry, has been studied and found to be a viable option for partial coarse aggregate replacement, capable of producing normal-weight concrete suitable for non-structural applications (Eziefula et al., 2018). In addition, the use of recycled concrete aggregate in fly-ash concrete is another sustainable approach that not only reduces the density and compressive strength but also has a higher rate of drying shrinkage at early and long-term ages (Bostanci et al., 2018). Using recycled aggregates such as crushed construction waste and industrial by-products not only helps reduce the depletion of natural resources but also addresses the challenges posed by waste management.

Technological innovation

As an add-on innovation, CCUS also plays a role in transforming the concrete industry into a more sustainable sector. However, CCUS is still in its early stages and will need to lower global CO2 emissions substantially from the cement sector. CO2 transport and storage infrastructure have to be built up (Schneider, 2019). CCUS is the main strategy to reduce CO2 emissions by more than 50%, but it requires a large financial investment and high energy quality, both of which affect the final cost of cement (Rocha et al., 2022). On the other hand, Ravikumar et al. (2021) provided an analysis that challenges the notion that CCUS always produces a net climate benefit. Their results indicate that depending on the source and utilisation of CO2, there can be scenarios with a net increase in CO2 emissions. Ensuring increased compressive strength from CO2 curing and reducing the electricity used in CO2 curing are strategies to increase the net CO2 benefit from CCUS (Ravikumar et al., 2021).

Design and construction strategies

Design for disassembly extends the life cycle of building materials by facilitating the easy separation and recycling of components. This approach is inherently sustainable as it allows for materials like concrete to be reused at the end of a building's life, thus reducing waste and the demand for new raw materials (Salama, 2017). The modular design theory, which groups parts into modules, enables parts to be removed in parallel, reducing the number of movements and reorientations needed to disassemble parts. This method can be used for most types of designs, enhancing the overall green design process (S. Smith & Hung, 2015).

3D printing in construction, particularly with concrete, introduces a shift by enabling the creation of complex geometries with minimal waste (Khan et al., 2021). This technology allows for the precise placement of material only where structurally needed, optimising resource use and potentially reducing the carbon footprint of concrete. The geometric and design flexibility afforded by 3D printing makes it possible to produce structural elements that are difficult to conceive with conventional formwork-based construction (Bhattacherjee et al., 2021).

2.1.2. Challenges for Implementing Green Concrete

During the literature review, approximately 37 academic studies were analysed to identify the challenges and opportunities associated with implementing green concrete, along with a range of solutions. Despite the diversity of enablers and barriers identified, these factors can be broadly categorised into four main groups—economic, institutional, social, and technical—owing to their shared characteristics and recurring patterns. This categorisation is also consistent with the classifications found in several scholarly articles within the literature (Liew et al., 2017; Sivakrishna et al., 2020; Suhendro, 2014).

Economic barrier

Concrete is a fundamental component in civil construction. The industry generally prioritizes the 'golden triangle' of project management—cost, time, and scope (Pollack et al., 2018). There tends to be a focus on minimizing upfront costs, often at the expense of potential savings over a project's life cycle through energy and material conservation (Busch et al., 2022; Henry & Kato, 2014; Suhendro, 2014). For example, specific studies on the use of green concrete in Asia have indicated that the adoption of recycled aggregates is limited by their higher cost compared to natural aggregates due to the availability of aggregate and recycling cost (Henry & Kato, 2014). In addition, a comparative cost analysis between geopolymer concrete and OPC concrete in Australia revealed that geopolymer concrete could be up to 39% more expensive than OPC (McLellan et al., 2011).

Moreover, the lack of incentive to pioneer the development of green concrete is also identified as a barrier by (Altarrazi et al. (2022)) due to the associated financial risks and market uncertainties. Without supportive measures like subsidies or tax breaks, the higher uncertain return on investment deters companies from pioneering this sustainable technology. Therefore, this situation results in a systemic economic lock-in, where end-users, suppliers, consultancy firms, and other stakeholders form a closed loop, favouring the purchase of conventional concrete over green concrete (Wesseling & Van der Vooren, 2017).

Furthermore, a fragmented supply chain is recognised as an obstacle to adopting green concrete (Busch et al., 2022). SCM, geopolymer concrete, and recycled aggregate depend on various industrial by-products from sectors such as power generation, agriculture, and manufacturing. Each industry has its own established supply chain, and integrating these waste materials often requires significant changes to these existing systems. The shrinking of the domestic market of cement was also identified as a barrier that created reluctance for the concrete suppliers to invest more in sustainable innovation (Henry & Kato, 2014). Furthermore, during the procurement process, green concrete increases the transaction cost (Busch et al., 2022). Another barrier comes from the country's specificity factors, such as free market mechanism and pure importing cement country (Henry & Kato, 2014).

Institutional barrier

The primary barrier to applying low-carbon concrete is the absence of supportive government policies (Henry & Kato, 2014; Suhendro, 2014). A notable example includes the deficiency of a carbon policy and guidelines to counter the economic disadvantages of low-carbon concrete in the marketplace (Makul, 2020). In addition, the barriers to adopting green concrete solutions in India are compounded by weak legislation, poor enforcement, and uncertainties regarding future legislation (Pati et al., 2023).

Furthermore, a study in Singapore highlighted that the lack of regulations concerning recycled materials hinders the implementation of recycled aggregate concrete, as the existing regulatory framework fails to encourage the use of waste materials in concrete production (Henry & Kato, 2014). In certain regions in North America, the absence of policies that mandate cement efficiency discourages design teams from optimising structures or concrete usage unless specifically requested by clients, leading to a reliance on standards. For instance, they will go for very regular 20 cm thick slabs (Habert et al., 2020). Consequently, innovative practices such as designing for disassembly and minimizing concrete usage are scarcely adopted. Furthermore, the absence of specific regulation, especially quality control, is also considered a barrier during the construction process of green concrete (Henry & Kato, 2014).

Furthermore, the complex relationships between stakeholders present a challenge to the implementation of green concrete (Henry & Kato, 2014). A successful application requires a mutual understanding among contractors, end users, engineering firms, and concrete suppliers. For example, vested interests have been identified in the Netherlands as a significant factor in perpetuating systemic lock-in, safeguarding established practices, and confining buyers to purchase conventional concrete (Wesseling & Van der Vooren, 2017). Moreover, the absence of a strong connection between the researcher and industry hinders the knowledge transfer process (Orozco et al., 2023). Scaling up green concrete projects to a larger scale also poses specific challenges.

The inadequate endorsement for green concrete from governmental and regulatory bodies is widely regarded as an obstacle (Choong et al., 2022). At the company level in India, a similar issue arises: insufficient commitment from top management is a barrier to implementing green concrete (Pati et al., 2023). Moreover, the absence of a comprehensive and integrative approach in the realms of engineering education and research is also seen as a hindrance at this stage (Suhendro, 2014).

A further significant challenge is the shortage of organisational resources. There are instances where many concrete technicians lack certification for managing new concrete mixtures in the Philippines, as the law does not mandate it (Orozco et al., 2023). In addition, within the contracting process, there is an obstacle in finding parties knowledgeable in implementing sustainable concrete (Henry & Kato, 2014; Paladan et al., 2022).

Social Barrier

The primary social challenge in adopting green concrete arises from the end users, who often lack the motivation to opt for alternative concrete solutions (Suhendro, 2014). This is supported by low public pressure for sustainability (Pati et al., 2023). In addition, there is a general reluctance to shift perceptions towards sustainability, with a preference for maintaining the status quo, thus creating resistance to change (Altarrazi et al., 2022; Busch et al., 2022; Suhendro, 2014).

Moreover, green concrete solutions, such as SCM and recycled concrete, which mainly utilise waste materials like fly ash, slag, or plastic, are often met with scepticism. Users and suppliers tend to assume these materials are of lower quality and may negatively impact the structure or building (Busch et al., 2022; Henry & Kato, 2014; Suhendro, 2014). Moreover, the perception that waste materials used in green concrete are associated with health risks and toxicity presents a further obstacle to their adoption (Altarrazi et al., 2022). Additionally, the benefits of sustainability or low carbon impact are often viewed as intangible and not readily apparent (Henry & Kato, 2014).

There is also a notable deficiency in the availability of information regarding the advantages and understanding of green concrete, which acts as a social barrier (Altarrazi et al., 2022; Orozco et al., 2023). For example, there is limited information regarding the mixture composition for geopolymer concrete to achieve standard engineering properties (Marinković et al., 2017). The scarcity of a proven track record for sustainable concrete and the lack of experience with green concrete usage foster hesitancy among practitioners (Altarrazi et al., 2022; Henry & Kato, 2014). Factors such as a lack of awareness, reluctance to adopt new technologies and inertia within construction regulations and norms are identified as obstacles impeding the decarbonisation of the concrete industry (Wesseling & Van der Vooren, 2017).

Technical Barrier

The conservative approach of codes and standards represents a technical barrier to adopting green concrete (Darko & Chan, 2017). SCM, such as fly ash, silica fume, and slag, demonstrate considerable variation in their chemical and physical properties based on their sources, complicating standardization and consistent performance (Skibsted & Snellings, 2019). These standards often dictate the use of specific materials and mix ratios rather than allowing for concrete to be specified by its functional or performance characteristics (Suhendro, 2014).

The absence of extensive field data on the lifespan and durability of green concrete is seen as broader to its acceptance. For example, the long-term behaviour of geopolymer concrete under diverse environmental conditions is still under investigation, with further study needed to explain its characteristics and possible limitations (Wong, 2022). The lack of comprehensive life cycle analyses and cost comparisons between OPC concrete and sustainable alternatives continues to challenge the development in this area (Hafez et al., 2019).

Technological risks are also viewed as barriers in the transition to green concrete. The early stage of technology development carries risks for the adoption of green concrete, with safety and durability concerns for its use in structural applications (Müller et al., 2014).

There are further challenges within the product development cycle. A pronounced disconnect exists between the initial incubation of green concrete and the readiness of these products for the marketplace (Sandbæk, 2023). Commercializing geopolymer concrete, for instance, faces difficulties such as a limited understanding of the mineralogy of aluminosilicate materials necessary for creating comprehensive bulk design mixes (Danish et al., 2022), as most research has focused on the engineering properties of geopolymer concrete. In addition, variability in the quality of concrete materials and structural integrity discrepancies impede green concrete's widespread application.

The construction industry's fast-paced schedule presents another obstacle (Henry & Kato, 2014). Infrastructure projects, typically operating under strict deadlines and commissioning targets, offer limited room for green concrete. Development of design requirements can introduce further delays (Busch et al., 2022). Furthermore, SCM like fly ash, slag, and silica fume need additional hydration time to attain full strength, as they react more slowly than OPC (Zeyad et al., 2021). A deficiency in infrastructure also inhibits the progress of CCUS, such as the CO2 transportation facilities.

Table 2.2: Summary of Barrier for Implementing Green Concrete

Aspects	Barriers	Codes
Economic	Higher initial cost	B-E1
	Lack of incentive to pioneer	B-E2
	Market uncertainties	B-E3
	Shrinking of domestic market	B-E4
	Fragmented supply chain	B-E5
	Transaction cost in procurement	B-E6
	Specific market mechanism	B-E7
Institutional	Deficiency of carbon policy and guideline	B-I1
	Lack of regulation for recycled material	B-I2
	Lack of regulation for concrete optimisation	B-I3
	Insufficient commitment from top management	B-I4
	Connection between education and industry sector	B-I5
	Organisational resources	B-I6
	Hard to find a knowledgeable partner	B-I7
	Complex stakeholder relationship	B-I8
Social	Lack of motivation	B-S1
	Preference for maintaining status quo	B-S2
	Negative perception of waste material	B-S3
	Intangible of benefit	B-S4
	Lack of experience and information	B-S5
Technical	Conservative codes and standards	B-T1
	Absence of lifespan and durability data	B-T2
	Lack of life cycle analysis data	B-T3
	Gap between incubation and ready-to-use product	B-T4
	Variation in quality of concrete materials	B-T5
	Fast pace construction schedule	B-T6

2.1.3. Enablers for Implementing Green Concrete

Economic Enabler

The carbon pricing policy has been acknowledged as a facilitator for the adoption of green concrete. These policies contribute to a more equitable materials pricing system, adjusting costs according to the CO2 emissions attributed to each material (Danish et al., 2022; Stokke & Kvellheim, 2020). Furthermore, the consideration of total embodied carbon during the procurement phase is also a derivative example of a carbon pricing scheme (Liew et al., 2017). For instance, there is a practice of concrete credits using a green star rating in Australia that creates economic viability for alternative concrete (Illankoon et al., 2018). This approach in the tendering process, which weighs both quality and cost, also supports green concrete (Sandanayake et al., 2020). The Most Economically Advantageous Tender (MEAT) criterion in European procurement considers cost, quality, and sustainability aspects, including carbon footprints, when making award decisions (Adaloudis & Bonnin Roca, 2021).

Furthermore, discontinuing fuel subsidies is considered an enabler, addressing the substantial indirect emissions from fuel used in the calcination process (Busch et al., 2022). Constraints on natural resources in Japan and Korea also motivate concrete suppliers to seek out economical replacement materials for aggregate or limestone (Henry & Kato, 2014). Furthermore, the provision of voluntary incentives to fund research and the development of green concrete serves as a catalyst, driving the industry towards alternative concrete solutions (Busch et al., 2022; Di Filippo et al., 2019). For instance, the EU Emissions Trading System (ETS) introduced an innovation fund for the development of CCUS in the cement industry between 2020-2030 (Adetunji et al., 2003). In addition, the concept of design optimization and efficiency also encourages the reduction of concrete in the building, as this concept can motivate stakeholders to minimize the project's budget.

Institutional Enabler

Government regulations and supportive policies are widely recognised as primary facilitators (Di Filippo et al., 2019; Sandbæk, 2023). For example, the European Union has mandated that member countries must achieve up to a 95% reduction in GHG emissions by 2050 (Ministerie van Economische Zaken, 2019). This directive has propelled various industries effectively, including the cement sector, to adopt decarbonisation strategies. In Singapore, implementing the Green Mark certification system has similarly spurred the adoption of alternative concrete solutions, ensuring measurable progress in developing green concrete technologies (Henry & Kato, 2014).

Formal agreements within the concrete supply chain are also instrumental in promoting sustainable concrete practices. In the Netherlands, the Dutch Concrete Agreement involves collaboration between concrete suppliers, government, engineering consultancies, and demand organisations to ensure the implementation of low-carbon concrete (Akkord, 2018). Establishing a clear and measurable plan is another enabler in this transition. In Europe, the CEMBUREAU Roadmap has been developed to outline short, medium, and long-term efforts for decarbonising the concrete industry, with these initiatives translated into multiple life cycles and measurable objectives (Association, 2020).

Additionally, the rise of green public procurement is critical in driving the market towards green concrete implementation (Stokke & Kvellheim, 2020). This procurement strategy encourages concrete suppliers, engineering companies, and contractors to use green concrete in order to enhance their competitiveness during the tendering process. This practice is supported by the procurement of innovation, a methodology that creates a risk-tolerant environment for the development of new solutions. For instance, as geopolymer concrete is still reaching maturity, specialised procurement methods can level the playing field for such nascent products. Furthermore, the integration of sustainability goals within the corporate and organisational objectives also as an enabler for the broader adoption of green concrete in the future

Social Enabler

The growing internal value among society bolstering the implementation of green concrete (Sandbæk, 2023). This commitment can empower top management within organisations to transform their sustainability vision into tangible actions (Marinelli & Janardhanan, 2022). Furthermore, an increased focus on disciplines, such as sustainable and circular construction, further facilitates social improvement within a company or organisation. For instance, in UK construction contractors, the adoption of sustainability pillars in the company has a major positive impact on organisational competitiveness (Adetunji et al., 2003).

The execution of pilot projects involving green concrete in low-risk areas, such as pedestrian zones, serves to enhance stakeholder perceptions and catalyse a shift towards green concrete (Danish et al., 2022; Nitichote & Yodsudjai, 2022). For instance, there is a successful project of implementation of recycled aggregate concrete in Czech that improves public perception towards recycled material in the construction industry (ERC-TECH, 2024). Region-specific issues, like waste management issues in places such as Singapore, also put pressure on the transition to green concrete, which often incorporates industrial by-products (Henry & Kato, 2014).

In addition, the extensive sharing of information can raise public awareness and foster the diffusion of knowledge between procurers and suppliers about the significance of green concrete (Busch et al., 2022; Wesseling & Van der Vooren, 2017). This trend is complemented by a societal shift towards durability-focused and life-cycle-oriented thinking, which is anticipated to further contribute to the development of green concrete in the future (Miller et al., 2021).

Technical Enabler

The primary technical catalyst for applying green concrete is the promising reduction of the carbon footprint, particularly for substituting the OPC manufacturing process. Carbon dioxide emission reductions up to 80% have been reported in the literature when alkali activate bases are used in place of OPC (Sivakrishna et al., 2020). The potential for combinations of OPC and green concrete methods facilitates a smooth and incremental transition to sustainable concrete (Suhendro, 2014). For example, SCM concrete offers the technical potential to integrate fly ash components up to 40% of the cement mix (Li et al., 2022). In addition, OPC can be processed with recycled aggregates during the concrete production process (Mesgari et al., 2020). These examples of hybridisation pave the way for a gradual transition, enhancing market acceptance.

Further technical benefits have been recognised in green concrete. For instance, geopolymer concrete exhibits enhanced durability in harsh conditions, such as carbonation, acid corrosion, sulfate exposure, elevated temperatures, and chloride penetration (Chen et al., 2021). Concrete mixtures incorporating fly ash in place of a portion of OPC have demonstrated increased compressive, tensile, and flexural strength, underscoring fly ash's contribution to the mechanical properties of concrete (Shehab et al., 2016). Employing industrial waste materials in concrete production is promising for reducing the environmental footprint and addressing waste management issues (Golewski, 2021). Furthermore, introducing various solutions aimed at decarbonising the concrete industry, which applies across nearly all phases of concrete's life cycle, enhances a comprehensive and multifaceted approach to the development of green concrete (Miller et al., 2021).

Table 2.3: Summary of Enablers for Implementing Green Concrete

Aspects	Enablers	Codes
Economic	Carbon pricing policy	E-E1
	Weighing price and quality in tender	E-E2
	Discontinuation on fuel subsidies	E-E3
	Lack of natural resources	E-E4
	Voluntary incentive for research	E-E5
	Optimisation and efficiency	E-E6
Institutional	Government regulation and policies	E-I1
	Formal agreement between stakeholders	E-I2
	Measurable roadmap development	E-I3
	Green public procurement practice	E-I4
	Integration of sustainability in organisation vision	E-I5
Social	Internal value	E-S1
	Disciplines in sustainability and circular	E-S2
	Promotion of pilot project	E-S3
	Waste issue	E-S4
	Information sharing	E-S5
	Life-cycle oriented thinking	E-S6
Technical	Proven reduction on CO2 emission	E-T1
	Ability to combine with conventional concrete	E-T2
	Technical advantage (durability, strength, etc.)	E-T3
	Various solutions in concrete life-cycle	E-T4

2.2. Sustainable Transition Theory

2.2.1. Multi-level Perspective (MLP) Theory for Sustainable transition

Transition theory emerged as a response to the need for a comprehensive understanding of significant environmental challenges, such as those found in energy, transport, and agri-food sectors (Geels, 2010). Incremental improvements cannot solve these problems but need radical change to new types of socio-technical systems, which are called 'sustainable transitions' (Elzen et al., 2004; Grin et al., 2010). Sustainable transitions were identified as multi-dimensionality and co-evolution, multi-actor process, stability and change, long-term process, open-mindedness and uncertainty, values, contestation, disagreement, and normative directionality. These transitions, however, are not easily achieved due to fundamental barriers within the current systems, including the lock-in effects associated with sunk investments, established behavioural patterns, vested interests, infrastructure, subsidies, and regulations (Geels, 2010). Geels posited that the transition process must involve the interplay between human agency, social structures, and organisations to ensure the functional application of technology that later was defined as the socio-technical system.

In the study of sustainability transitions, MLP is often used as a primary framework. This approach, introduced by Kemp et al. (1998b) and further developed by Geels (2002, 2004) in subsequent works, as well as Geels and Schot (2007), categorises the transition process into three different levels: niches, where radical innovations emerge; socio-technical regimes, which represent stabilised systems across various dimensions; and an exogenous socio-technical landscape that influences and is influenced by the other levels (Elzen et al., 2004; Geels, 2002; Geels & Schot, 2007).

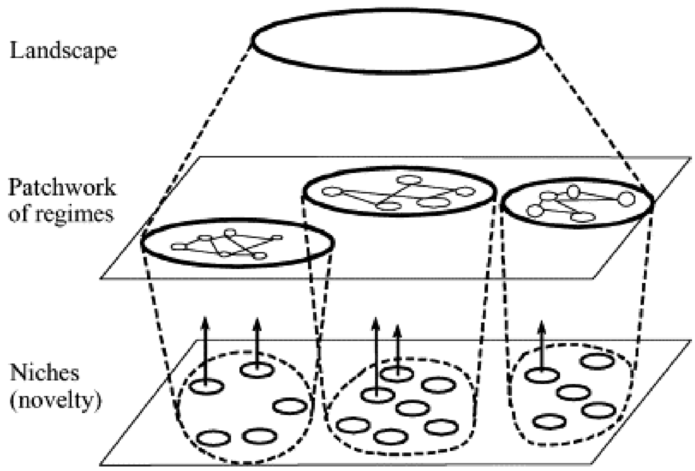

Figure 2.1: Multiple levels as a hierarchy (**p. 1261**; Geels, 2002)

Landscape

In the socio-technical system hierarchy, the landscape is the highest level, characterised by its hardness and material context, such as the physical and spatial configurations of cities, industries, transportation, and energy infrastructures (Geels, 2002). At the landscape level, change typically occurs at the slowest pace, influenced by cultural shifts, demographic movements, and political transformations (Geels, 2002). The landscape serves as an overarching framework within which actors interact; it comprises slowly evolving external factors that establish the direction and pace of change within the system (Geels, 2002). The socio-technical landscape, in this context, exhibits a degree of stability comparable to natural elements like soil quality and geographic features, resembling the gradual progression seen in biological evolution (Geels & Schot, 2007). This layer is a backdrop, generating a structural influence and imposing a top-down directive that impacts the development and behaviour at the niche and regime levels (Köhler et al., 2019). Examples of the landscape layer can be seen in the current aviation sector, which is dependent on fossil fuels, or the practices of democracy across countries in the world.

Socio-technical Regime

The socio-technical regime represents the meso-level in the MLP, characterized by the stability of existing technological developments (Geels, 2002). At this level, technological developments are already well-integrated with other dimensions of the social framework, including policy, market dynamics, user preferences, industry, science, and culture. Examples of such regimes include energy systems or public transportation networks in specific countries. This stability in the regime is dynamic, meaning that innovation still occurs but is typically incremental. The regime's stability is reinforced by various forms of power, such as regulative, cognitive, and normative (Köhler et al., 2019). Actors leverage resources such as positions of authority, finances, media access, personnel, and capabilities to interact with others and pursue their goals and interests (Geels, 2014).

The regime is also associated with incumbent or defensive actors who oppose, postpone, or disrupt the process of transitioning towards innovative niches (Köhler et al., 2019). Despite apparent stability, there is a continual underlying struggle for power within the regime, involving conflicts between established entities and emerging niche innovations. This struggle manifests in actions like contestation, lobbying, forming coalitions, and negotiating. Moreover, regimes are subject to change, not just from niche pressures but also through a gradual process of systemic reconfiguration. This process reflects a cumulative incremental regime change, shifts in relative sizes of regimes, regime alignments, component substitution, and symbiotic adoption (Geels, 2018). In addition, two dimensions of the adaptation process in the regime were also identified based on the availability of resources (factor endowments, capabilities, knowledge) and degree of coordination of resource deployment (Geels & Schot, 2007).

Technological Niches

Niche represents a protected space that allows for the experimentation and development of radical innovations that deviate from the dominant regime (Schot, 1998). Such radical technologies require protection from the 'normal' market as they are not 'ready-made,' and there may be deep uncertainties (Geels, 2019). Niches serve as critical environments for learning processes such as learning by doing and using (Geels, 2018). However, these radical innovations often struggle to transition beyond their niche origins due to higher costs and lack of economies of scale and incremental changes that the established regime has (Geels, 2018; Geels, 2019).

Köhler et al. (2019) introduced a classification of core processes within niches, including shielding, nurturing, and empowering, which contribute to the strategic management of these niches (Raven et al., 2016; A. Smith & Raven, 2012). The processes internal to niches have been articulated within the framework of Strategic Niche Management (SNM), a field that has been informed by the work of Kemp and colleagues, as well as Hoogma's contributions (Kemp et al., 1998; Rotmans et al., 2001).

Niches leverage relational power and networking to gain influence and empower themselves (Köhler et al., 2019). There's a growing recognition of the need to explore the synergies and competitions between multiple, concurrent technological developments or niches and their effects on the broader systemic functions (Papachristos et al., 2013; Sandén & Hillman, 2011). Research has evolved from focusing on state-driven, singular, Western-centric projects to analysing more decentralised, civil, and networked experiments that span various geographical realms (Castán Broto & Bulkeley, 2013). The collective impact of these multiple niche innovations holds the potential to replace existing regime components (Geels, 2018).

Table 2.4: Summary of MLP Characteristics

Characteristics	Niche	Regime	Landscape
Dimensions	Technological	Socio-Technical	Socio-Technical
Innovation level	Radical	Incremental	Gradual
Interaction	Protected from normal market	Aligned with policies, market, culture, social etc.	Aligned with policies, market, culture, social etc.
Level	Localised	National/City	Backdrop
Enabler of change	Dominant design, windows of opportunity	Pressure from niche, weakening of regime, regime dynamics	Cultural shift, demographic movement, political transformation
Change mechanism	Evolution and variation	Selection	Selection

2.2.2. Transition Mechanism of MLP

Niche Development

The transition begins with radical innovation at the niche level. This development can emerge from pressures exerted by regime changes and landscape changes, as identified by (Köhler et al. (2019)). Niches may create linkages between them, providing a trajectory for future development, which is illustrated by small dotted arrows in Figure 1.2. Niche innovations have the potential to evolve into a 'dominant design' when a series of projects cumulatively enhance each other. This maturity occurs through the sharing of experiences and learning activities (Geels, 2019). And focused efforts to consolidate knowledge. Such efforts include codifying, standardising, and creating models that define industry best practices, establish product specifications, and set forth design guidelines (Geels, 2019).

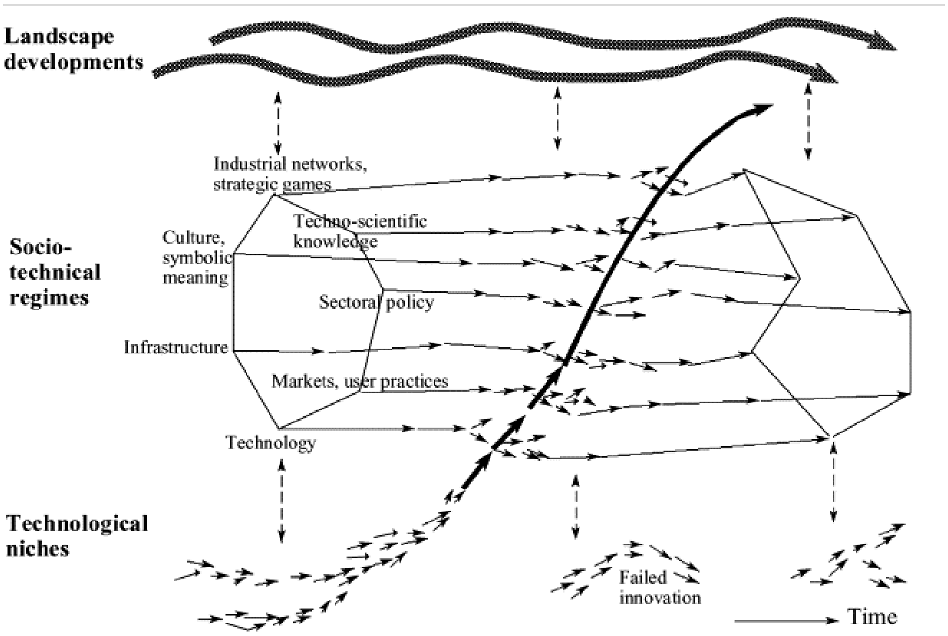

Figure 2.2: A MLP on technological transition (**p. 1263**; Geels, 2002)

Breakout Mechanism

Radical innovations can break out from the niche level when regime and landscape-level processes create a "window of opportunity." There are two mechanisms during this breakout process: technological add-on or hybridisation and riding on growth in specific markets (Geels, 2002). This breakout occurs gradually as radical innovations find application in subsequent domains or market niches, effectively accumulating niches. Several indicators signal when niches are ready to break out: learning processes have converged on a dominant design, key players have joined the support network, there have been price/performance enhancements with expectations of further improvements, and the innovation achieves more than 5% market share across cumulated niches (Geels & Schot, 2007).

Windows of opportunity may arise from tensions in the socio-technical regime or shifts in the landscape that pressure the regime. Moreover, these opportunities can emerge at the regime level due to a weakened or destabilized regime, reducing resistance to acceleration policies, or focusing events like wars, economic crises, or oil shocks (Roberts & Geels, 2019). At this level, the regime is a selection and retention mechanism for niche innovations. However, barriers can inhibit the breakout process, including various lock-in mechanisms that favour incremental innovation within the existing regime (Geels, 2019).

The radical innovation can transform not only technological aspects but also other dimensions such as regulation, infrastructure, symbolic meaning, and industrial networks. Once established, a new socio-technical regime may drive changes at the landscape level (Geels, 2002). In addition, more research has also focused on actors' roles in this transition process, including users, civil society actors, cultural discourses, and firms to help the breakout of the transition process (Schot et al., 2016).

Alternative Transition Pathways

Aside from the bottom-up, niche-to-landscape transition mechanism, the transition process has been reformulated to include substitution, transformation, reconfiguration, de-alignment, and realignment processes (Geels et al., 2016). In the substitution approach, the socio-technical regime is regarded as the incumbent, while the niche is seen as the challenging entity aiming to compete with the incumbent. Transformation refers to a regime change that involves either an internal search within the current layer or the pursuit of new alternatives at the niche. Reconfiguration represents the formation of a new alliance between the existing regime and radical innovations to maintain the current regime's status. De/re-alignment may occur as a result of the regime's failure, which is often triggered by external pressures from the landscape (Geels et al., 2016). Patterson et al. have also created classifications focusing on change processes: socio-technical transitions, socio-ecological systems, sustainability pathways, and transformative adaptation, which suggest strategies should not only accommodate change but also create new alternatives (Geels, 2019).

Incremental regime improvements, changes in regime sizes, or new interactions between niche and regime elements can also lead to significant transition pathways, as empirical investigations have shown (Geels, 2018). Furthermore, various studies have indicated that established actors are capable of shifting their focus towards radical niche innovations (Berggren et al., 2015; Penna & Geels, 2015). It has also been observed that incumbents across different industries are increasingly engaging with niche innovations (Hess, 2013). However, transitions may shift between pathways, depending on technology deployment and institutional struggles (Geels et al., 2016).

Table 2.5: Summary of Transition Pathways

Pathways	Definition	Mechanism
Breakout mechanism	A niche reaches a point of consolidation, breaks out into the mainstream regime, and begins to interact successfully with established systems.	Bottom-up
Substitution	This pathway involves new firms challenging established incumbents, resulting in a shift of dominance.	Bottom-up
Transformation	Incumbents make incremental adjustments to their search routines and procedures.	Internal layer
	A substantial reorientation towards entirely new technologies or adopting new beliefs, missions, and business models.	Top-down
Reconfiguration	Formation of new alliances between established incumbents and new market entrants.	Top-down & Bottom-up
De/re-alignment	Incumbents may fail due to pressures from the broader landscape, which in turn clears the field for new entrants.	Top-down

Accelerating Transition Process

Geels et al. (2017) propose several strategies to accelerate the breakout process of transition. Geels proposed applying dynamic policy mixes over isolated instruments, recognising the complex and prolonged nature of transitional processes. It's impractical for policymakers to depend solely on a single policy instrument, given the multifaceted nature of transitions. For example, strategically timing various policies—financial, regulatory, and programmatic initiatives—can create 'windows of opportunities' at a regime level. Furthermore, expanding the range of solutions beyond just supply-side technology and economic considerations is critical to engaging more actors in the transition process. For instance, the benefit of radical innovation should be promoted from other points of view, such as cultural and social. Therefore, the transition process would get supportive pressure from those additional stakeholders.

Additionally, it is crucial to manage the phasing out of old technologies while simultaneously fostering innovation to build momentum for breaking to the regime level. This includes not only developing solutions but also scaling up niche innovations. Moreover, a comprehensive approach should also focus on the analysis of politics alongside policy. Niche innovations require significant support from policymakers, who can provide a protected environment for experimentation and regulatory changes that facilitate the breakout process. In addition, policymaking is also recognised as a political process that entails negotiations, compromises, and coalition-building with stakeholders.

2.3. Sustainable Project Management Concept

According to the Project Management Institute (PMI), project management entails applying knowledge, skills, tools, and techniques to execute tasks and deliver value to achieve desired outcomes (). It encompasses planning, organizing, leading, and controlling resources to fulfil specific objectives within a given timeframe and budget. In construction projects, project management includes various practices such as feasibility studies, risk assessments, scope development, design, procurement, contracting, monitoring and control, and project closure (Munns & Bjeirmi, 1996).

The construction industry must adapt to address significant challenges like climate change, sustainability, circularity, and GHG emissions. Thus, the project management body of knowledge (PMboK), a notable set of standards and guidelines for project management, advised adaptations to the best practices should be made according to project characteristics (Rose, 2013), supporting the notion that no single approach fits all projects (Shenhar, 2001).

Incorporating sustainability into project management affects both the deliverables and the delivery process. Deliverables may involve changes in project specifications, requirements, quality criteria, and materials. Regarding delivery, changes should be reflected in recognition of project context, stakeholder engagement, team organisation, project sequencing, scheduling, risk management, communication, handover, and organisational learning (Silvius, 2017).

B.-G. Hwang et al. (2013)identified specific challenges to integrating sustainability into project management, including extended pre-construction time, difficulty in selecting sustainable (sub) contractors, uncertainty regarding sustainable equipment and materials, higher costs, increased coordination with consultants and specialist engineers, frequent design variations during construction, difficulties in embedding sustainability into contracts, unexpected circumstances in project completion, and planning in unconventional sequences with alternative construction techniques.

2.3.1. Strategic Shift in Project Management

According to the literature review, several shifts in traditional project management are needed to encourage sustainability innovation in project management. The approaches will be elaborated on, from general strategies to more detailed suggestions for each project phase. Starting with the project goal, a paradigm shift in project management is needed by prioritising the triple bottom line of sustainability —economic, environmental, and social (Gimenez et al., 2012)– over the traditional iron triangle —time, scope, and budget (Pollack et al., 2018). In addition, Robichaud and Anantatmula (2011) recommend beginning with the end in mind when adopting sustainability.

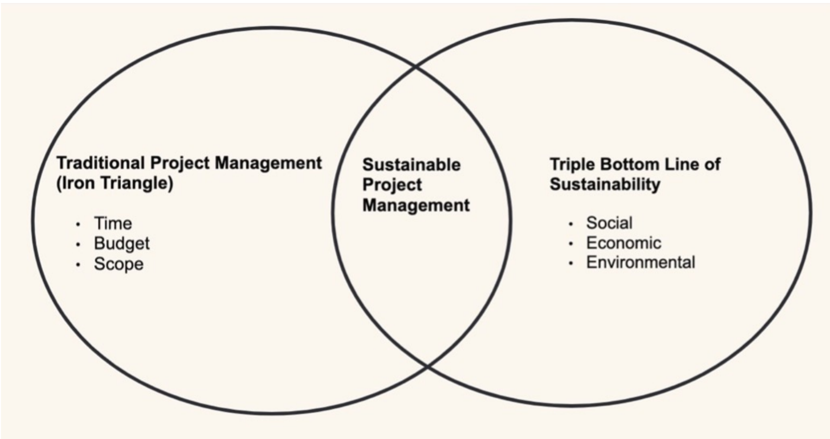

Figure 2.3: Sustainable Project Management: Shift in Goals

In the time horizons, life-cycle management and decision-making should be emphasized (Marcelino-Sádaba et al., 2015). Considering both product and project life cycles is crucial for integrating the sustainability of the project (Labuschagne & Brent, 2005). Extended life cycles after project closure are also mandatory to adopt sustainability (Koke & Moehler, 2019).

Moreover, a significant shift from a 'management of stakeholders' approach to a 'management for stakeholders' approach is observed in stakeholder management. In traditional project management, stakeholders are often viewed merely as "resources" that provide budget or approval. It is recommended to change this perspective and consider stakeholders' interests and accommodate them accordingly (Julian et al., 2008). In addition, it is recommended that the influence of incorporating sustainability goals across all sub-processes of project management be equally distributed.

In the governance approach, research indicates that sustainability has the most significant impact on planning and execution and the least on initiation. Acknowledging these differences is vital for sustainable project management and establishing the right balance (Toljaga-Nikolić et al., 2020). Balancing stability with flexibility is also suggested for managing innovative projects (Kale & Singh, 2009). Additional attention should be given to corporate policies, resource management, and organisational learning, which provide a high-level overview of sustainable project management (Armenia et al., 2019). An innovative conceptual framework based on the dimensions of products, processes, organisations, and managers is also proposed.

In the methodology, agile methodologies are suggested in sustainable project management due to their advantages in handling project unpredictability and emphasising people and creativity over processes (Ciric et al., 2018). This contrasts with the traditional ”waterfall” approach, which relies on deliberate planning and control. Agile methods positively impact sustainability by improving stakeholder communication and cooperation, flexibility in innovation, efficiency, and speed in innovation's predevelopment stages, delivering customer expectations, early deficiency detection through iterative testing, and fostering collaborative project planning with shared responsibility (Ciric et al., 2018). Design thinking is also utilised in sustainable project management for its emphasis on an exploratory phase where requirements and specifications emerge through learning and trial and error. This approach also underscores the importance of stakeholder involvement and the need to integrate project management with corporate strategising (Ben Mahmoud-Jouini et al., 2016).

Table 2.6: Differentiation between conventional and sustainable project management

Aspects	Project Management	Sustainable Project Management
Goals	Golden triangle: budget, scope and time	Adding triple bottom line: economic, environment, and social sustainability
Time horizon	Within project lifecycle	Extend beyond project lifecycle to product lifecycle (e.g. maintenance, use and end of life)
Stakeholder	‘Management of stakeholder’, perceive them mainly as a resource	‘Management for stakeholder’, perceive their interests in project
Governance	Dominance in stability and deliberate planning	Combine stability and flexibility
Methodology	‘Waterfall’ and linear approach	Open to use agile and/or design thinking

Looking into a more detailed process, the adaptation for sustainable project management is elaborated through several phases of the project lifecycle, including feasibility or initiation, design, procurement, and monitoring and control. This classification is adapted from the general process of the Project Management Institute (PMI) and the construction industry's best practices.

2.3.2. Shift in Feasibility Phase

McGrath and MacMillan (1995) advocate for a discovery-driven approach in managing the initial phase, which involves formulating and refining hypotheses through experimentation to yield verified knowledge (Ben Mahmoud-Jouini et al., 2016; Conforto et al., 2014). This approach, coupled with design thinking - a problem-solving-oriented mindset discipline - addresses stakeholder management within the exploratory phase of a project (Ben Mahmoud-Jouini et al., 2016). Expanding the parameters to project feasibility studies is also recommended. For example, Shen et al. (2010) suggests incorporating 18 economic, nine social, and eight environmental performance attributes into feasibility analyses (Shen et al., 2010).

There is an argument for utilizing the cost-benefit analysis to balance economic and ecological outcomes (Robichaud & Anantatmula, 2011). Conventional investment return methods, such as discounted cash flow and payback period, fall short when considering environmental and social dimensions. Thus, a multi-criteria business case evaluation that integrates sustainability indicators is necessary (Silvius, 2015; Silvius, 2017). Moreover, specific instruments for assessing the sustainability aspects of a project have been developed, such as the Sustainable Footprint Methodology and the Sustainable Project Management Maturity Model (Oehlmann, 2010; Silvius, 2017).

2.3.3. Shift in Design and Planning Phases

Bovea and Pérez-Belis (2012) identified three key elements for optimizing sustainability in design: early incorporation of environmental factors, a focus on life cycles, and a multi-criteria approach (Marcelino-

Sádaba et al., 2015). The discipline of Design for Environment (DfE) is introduced to integrate social, economic, environmental, and institutional aspects, allowing for greater participation and the expression of unique identities beyond the consumption of standardised products (Marcelino-Sádaba et al., 2015; Spangenberg et al., 2010).

However, only adding environmental requirements at scope development may prove insufficient. As projects advance through phases, differing pressures can redirect their trajectory, influenced by stakeholder perceptions, environmental engagement, responses, and the microprocessor employed (Corbett et al., 2018). Furthermore, integrating environmental aspects into product development is deemed effective only if it results in mature products (Finkbeiner et al., 2006; Marcelino-Sádaba et al., 2015). Although products are developed operationally through projects, eco-design from a project management perspective is rarely addressed (Marcelino-Sádaba et al., 2015).

Emphasising life cycle costing in the budget shifts the focus from short-term ROI to long-term operational savings (Robichaud & Anantatmula, 2011). Consulting with contractors and suppliers is valuable for improving project understanding of the impact of alternative construction methods, materials, and plants on sustainability (Shen et al., 2010).

A more technical approach includes the Sustainable Breakdown Structure (SBS), which resembles sustainable development principles based on the triple bottom line throughout the project lifecycle (Marcelino-Sádaba et al., 2015). The Sustainability Management Plan (SMP) addresses sustainability risks and opportunities as part of the project planning documents (Carboni et al., 2018). Similarly, Projects Integrating Sustainable Methods (PRiSM) offer a project management methodology aligned with ISO 21500 project management processes (GPM, 2013).

2.3.4. Shift in Procurement Phase

Procurement is a crucial demand-side tool for addressing major challenges such as sustainability (Edquist & Zabala-Iturriagagoitia, 2012). The process includes translating identified challenges into specifications, refining the tendering process, enabling suppliers to convert these into technical specifications, and assessing tenders before awarding contracts.

Using functional specifications rather than detailed specifications during tendering is key to fostering innovation in sustainability. For instance, the functional specification will only specify the general goals of the project, such as the building capacity, while giving freedom to the contractor to determine which material or construction methodology will be used. Overly detailed specifications by procuring agencies can inhibit suppliers' creativity and innovation (Edquist & Zabala-Iturriagagoitia, 2012). The conversion of functional requirements into technical specifications demands advanced competence from suppliers.

Procurer-supplier interaction is also pivotal in this process. Interactive learning and a regulatory framework that encourages both cooperation and competition are important (Edquist & Zabala-Iturriagagoitia, 2012). Relational contracting is preferred for providing sustainable innovation in the project (Lenferink et al., 2013). Alliance project delivery models promote sustainability in multi-partner settings by providing mutual benefits and risk-sharing (Kivilä et al., 2017). In addition, an open-book subcontracting process is recommended for green projects (Robichaud & Anantatmula, 2011).

An alternative approach for procurement, Public Procurement for Innovation (PPI) in the public sector, categorized processes into Direct and Catalytic PPI based on the user (Edquist & Zabala-Iturriagagoitia, 2012). Direct PPI occurs when the procuring organisation is the end-user, whereas Catalytic PPI serves as a facilitator for end-users. The procurement process is also classified into Pre-commercial, Adaptive, and Developmental stages based on the product's maturity (Edquist & Zabala-Iturriagagoitia, 2012). Specific procurement strategies will be made according to the classification above. Flexibility, procedural simplification, life-cycle costing, and pre-procurement market consultations are approaches to integrate sustainability into procurement. In addition, Contracts should incentivise suppliers through performance agreements and bonuses (Pulaski et al., 2004).

2.3.5. Shift in Monitoring and Control Phases

The project manager's role is pivotal at this stage. The project sponsor focuses on deliverables, while the project manager has the opportunity to enhance project sustainability through organisation and execution (Silvius, 2017). Employing a seasoned green project manager, preferably a LEED-accredited professional, is highly recommended (Besner & Hobbs, 2008; Robichaud & Anantatmula, 2011).

Additionally, Earned Green Value Management (EGVM) is an alternative tool developed to adapt activities within project planning, such as using Work Breakdown Structures (WBS), organisational Breakdown Structures (OBS), and control accounts, all of which support sustainable project outcomes (Geels, 2002).

Table 2.7: Summary of shift on project management process

Process	Adaptation
Feasibility	Discovery driven (Explorative mindset)
	Perform cost-benefit analysis balancing economic and ecological
	Enlarge feasibility parameter
	Apply multi-criteria analysis instead of conventional investment assessment
	Move from ‘management of’ to ‘management for’ stakeholders approach
	Utilise tools, such as sustainable footprint methodology or project management maturity model
Design and planning	Incorporation of environmental requirements
	Life-cycle (costing) approach
	Use sustainable breakdown structure (SBS)
	Utilise tools, such as sustainability management plan (SMP) and projects integrating sustainable methods (PRiSM)
Procurement	Use functional specification instead of over-detailed specification
	Combine of cooperation and competition
	Perform more relational contracting, such as alliance
	Open book contracting
	Apply specific strategy according to public procurement innovation (PPI) scheme
	Do pre-procurement market consultation
Monitoring and control	Employ experienced project manager
	Utilise tools, such as Earn Green Value Management

2.4. Transition Management Governance

Modern society is transforming into a network society, leading to complex problems that traditional methods and institutions cannot solve. These problems are characterised by complexity, uncertainty, and conflicting perspectives (Tainter, 2006). Examples include over-consumption of resources, social and economic inequalities, biodiversity loss, and climate change (Tainter, 2006). Long-term structural changes are essential to address these issues. Traditional policies are insufficient for such complex and persistent problems, which present differently at various levels and involve multiple conflicting actors (Steiner & Posch, 2006).

Need for New Governance Strategies

These challenges require new governance strategies that consider complex system dynamics, uncertainty, interdependency, and interactions. In response to this urgency, Loorbach (2007) introduced the concept of transition management. The main methodologies for developing transition management theory include theory development, practical experimentation, and participatory action research.

Following the study, Loorbach (2007) introduced the multi-level governance framework, which distinguishes transition management activities into three levels: strategic, tactical, and operational. These levels are based on differences in the scale at which the issue is observed, the time frame considered, and the system level addressed. These levels are changing, with actors operating at different layers constantly interacting and the various activities influencing each other.

- Strategic Level: This level addresses the future of the system, including its underlying culture, structure, and practices, within the context of a changing world and external pressures.
- Tactical Level: At this level, domain or sector-specific and interest-driven governance activities take place, such as agenda-setting, lobbying, and coalition-building.
- Operational Level: This level encompasses all concrete actions and innovations that align with the vision, including new technologies, concepts, ideas, regulations, consumer behaviour, financial constructions, and institutions.

The concept of transition management mirrors the nature of transitions. In the initial phases of a transition, the system as a whole is the subject of discussion and study. In later phases, as the process of fundamental change becomes more concrete, the focus of governance shifts to lower system levels.

Table 2.8: Transition Management activity types

Problem Level	**Time-scale**	**System Level**	
Strategic	Abstract/societal system	Long-term (30 years)	System
Tactical	Institutions/regime	Mid-term (5-15 years)	Sub-system
Operational	Concrete/project	Short-term (0-5 years)	Niche/'mini'-system

Interaction between and within Levels

According to the multi-level framework for transition management, Loorbach (2007) explains that the three levels are looping, meaning they consist of the same basic modules they distinguish. Activities at different levels can also be ordered according to these three levels. For example, an operational project will also have a strategic ambition (to be realised within five years), an agenda, and daily operations. Similarly, at the strategic level, the ambition would consider the operational capacity of the organisation, which balances the ambition for long-term targets.

This iterative is presented because it allows for various interactions between and within the levels. In transition management practice, these interactions and their effects are unpredictable and not directly managed. However, because they align with the same overall direction and emerge within a network of actors, they can significantly contribute to collective goals.

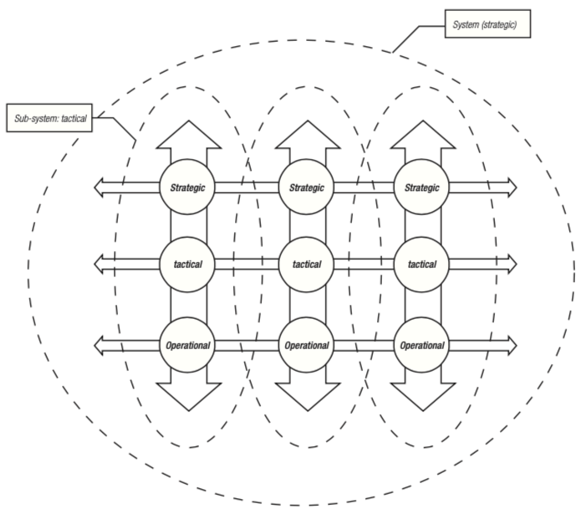

Figure 2.4: (Recursive) Governance System **p. 113**; Loorbach, 2007)

3 Preparation and Methodology for Empirical Study

This chapter outlines the preparatory steps for the empirical study approach used in this research. The study will conduct an in-depth qualitative analysis that is divided into two main sections, which is the macro level for understanding the current status of the green concrete transition in the Netherlands and the micro level for understanding the barrier and challenge for implementing green concrete in the project level in according to the demand side. Then, following the input from those two levels, the strategy for accelerating green concrete adoption will be developed. In general, below is the overall workflow for empirical study.

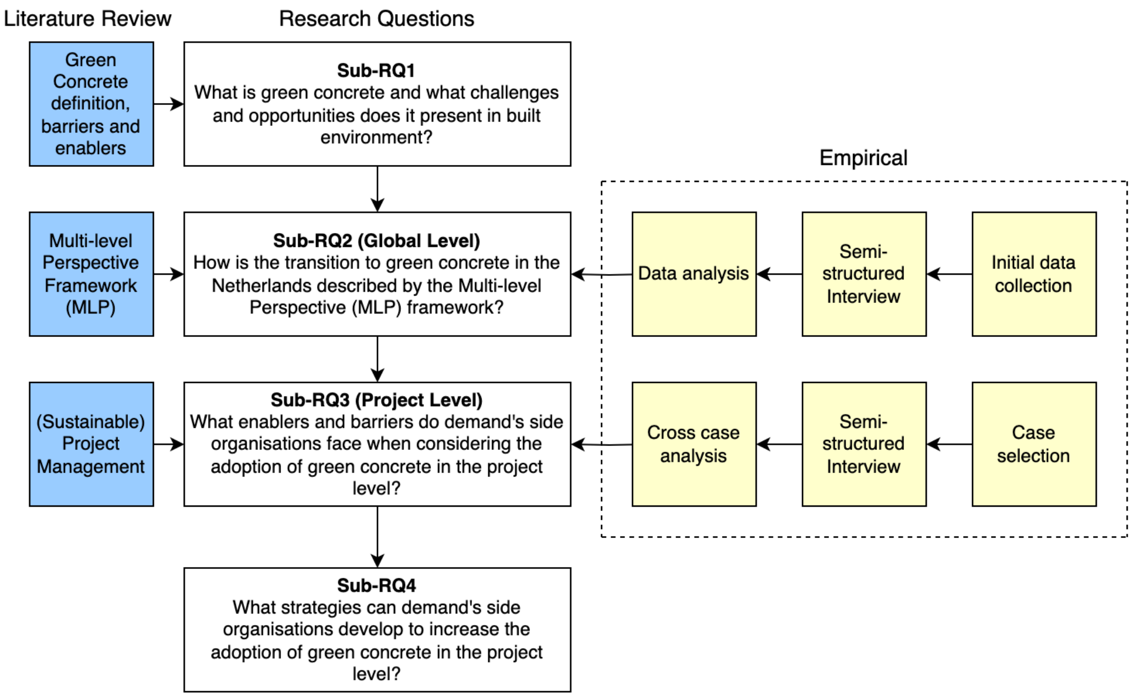

Figure 3.1: Empirical Study in Overall Research Flow

3.1. National Level: Understanding the status of green concrete transition in the Netherlands

The empirical study for understanding the green concrete transition in the Netherlands will follow the structure of the MLP for technological transition (Geels, 2002). In general, the preparation and methodology of the research would follow the necessary information from the chosen framework.

3.1.1. Initial data collection

This stage involves a data collection approach that gathers information from websites and public documents relating to the green concrete transition in the Netherlands. There were several examples of keywords employed, such as "concrete agreement," "duurzaam Beton," and "betonakkord." The data collected from websites and public documents will serve multiple purposes. Firstly, it will help form a robust background for the study, ensuring the research is grounded in real-world information. Secondly, this data will assist in developing more informed and targeted questions for the subsequent semi-structured interviews. By entering the interview phase with a deepened understanding of the subject matter, the researcher can engage more effectively with participants, probing deeper into specific areas of interest and exploring insight that may not be immediately evident from public sources alone.

This process uses websites and public documents, including public client organisation websites, cement producers, concrete associations, concrete agreements, contractors, and other related publications.

3.1.2. Semi-structured interview

After reviewing the initial information, the research continued to the main empirical component: semi-structured interviews. This research aims to understand the current status of the transition to green concrete in the Netherlands, making insights from individuals involved in this sector through interviews incredibly valuable. Semi-structured interviews were utilised to provide the present state of green concrete implementation within the framework of MLP (Geels, 2002). This approach involved posing open-ended questions, preferable to structured or non-structured questions, as they allow for more comprehensive information through the potential for follow-up inquiries (Kallio et al., 2016). Furthermore, this section will outline the criteria for selecting interviewees and the established interview protocols.

Criteria for interviewee selection

For conducting research on sustainable concrete in the Netherlands, selecting the right interviewees is important to gaining comprehensive insights into the sector. The criteria for choosing interviewees should be designed to ensure a well-rounded understanding of the diverse aspects and challenges associated with green concrete. Here's a detailed explanation of the criteria to guide the selection of interviewees:

1. Experience with green concrete initiatives
   Interviewees should demonstrate involvement or interest in green concrete initiatives, whether through previous projects, current roles, or published works. For instance, candidates actively involved in the national concrete agreement (betonakkord), concrete coalitions, and related publications were initially identified.
2. Geographical limitation and Sectoral Representation
   Ensure a mix of perspectives from various concrete sectors within the Netherlands to capture any expertise differences in the green concrete transition. Include professionals from both public, private, and non-profit sectors to understand different motivations and constraints encountered in the adoption of green concrete.
3. Influence and Decision-Making Capacity
   Select individuals who are decision-makers or have significant influence over the construction, procurement, design, or policy aspects related to green concrete.
4. Willingness to Participate
   Choose interviewees who are willing and available to participate in the research. Their willingness can greatly affect the depth and quality of information they provide during the interviews.

Table 3.1: Interview Details of Experts

Actor	Category	Role	Experience	Date of Interview
EXP1	Concrete chain coalition	Committee member	50 years	15/April/2024
EXP2	Contractor	Concrete specialist	11 years	19/April/2024
EXP3	Public client organisation	Advisor	19 years	19/April/2024
EXP4	Cement association	Technical advisor	28 years	24/April/2024
EXP5	Material supplier/Innovator	Manager	20+ years	23/April/2024
EXP6	Cement producer	Manager	26 years	29/April/2024
EXP7	Consulting engineering company	Advisor	26 years	25/April/2024
EXP8	Buyer group coalition/local public client	Executive advisor	32 years	24/April/2024
EXP9	New alternative cement company	Material specialist	32 years	26/April/2024
EXP10	Innovation evaluator	Committee member	16 years	21/May/2024
EXP11	Public client organisation	Technical advisor	16 years	5/June/2024
EXP12	Research technology company	Top management	25 years	26/June/2024

Twelve experts representing sectoral variation within the Netherlands were selected. All interviews were conducted via online meetings.

Interview Protocol

1. Initial Contact and Scheduling:
   Around twenty introductory messages were sent via networking media platforms, followed by detailed interview invitations via email. These invitations included a short description of the research topic and objectives and were scheduled based on the availability and preferences of the participants to ensure maximum engagement and participation
2. Informed Consent Process:
   Accompanying the interview request, informed consent forms were provided to each potential participant. These forms outlined the data management procedures to be followed during the interview process. Key aspects covered in the consent forms included the agreement from interviewees to allow audio recording and transcription of the interviews. This step is crucial to maintain ethical standards and to assure participants of their privacy and the confidential handling of the information they provide.
3. Interview Format and Setting:
   The interviews were conducted online, except as specified by the candidates. The interview is planned to be 60 minutes, with 10 minutes of buffer time for the introduction and closing parts.
4. Interview contents
   The interview process begins with introducing the researcher and the interviewee, clearly stating the purpose of the research and the interview. Before starting the recording, the interviewer reminded the participants about confidentiality, as outlined in the informed consent form. The interview was divided into seven parts.
   (a) Explored the overall status of the green concrete transition in the Netherlands

(b) Focused on assessing the practicality and maturity of various green concrete alternatives within the country.

(c) Addressed the factors enabling the accelerated adoption of green concrete

(d) Followed by a discussion on the barriers to green concrete transition.

(e) Examined the socio-technical interactions during the green concrete transition.

(f) Explored into potential future transition models for green concrete.

(g) Concluded with questions about recommendations to promote green concrete from the demand-side perspective.

In each part, follow-up questions were tailored following the background and ongoing discussion findings.

5. Anonymity and Language:
All interviews were conducted and transcribed anonymously to maintain the confidentiality of the participants. The discussions and the resultant transcriptions were in English.

6. Transcription and Feedback:
Post-interview, the transcriptions were prepared and offered to the interviewees upon their request for any comments or corrections. This also provided an opportunity for interviewees to review the reflections and insights they shared, ensuring accuracy and thoroughness in the documentation

3.1.3. Methodology of data analysis

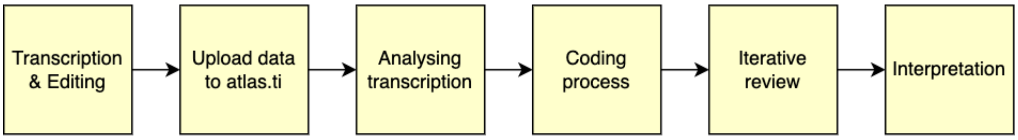

Figure 3.2: Workflow of data analysis

1. Transcription and Editing:
Interviews are transcribed automatically by Microsoft Teams. The transcriptions are then grammar-checked and edited to ensure accuracy before they are used for further analysis.

2. Uploading Data to ATLAS.ti:
The cleaned and edited transcriptions are uploaded to ATLAS.ti. This software facilitates the organisation and analysis of qualitative data, allowing for the coding, retrieval of quotes, and exploration of correlations between codes as referenced by S. Hwang (2008).

3. Analysing the Transcriptions:
The researcher reads through the interview transcriptions to identify key elements or findings such as beliefs, opinions, technology, barriers, and enablers of green concrete transitions.

4. Coding Process:
Codes and themes are applied to the transcriptions. The initial codes and themes are developed by the components of an MLP framework. This is an iterative process; as the analysis progresses, new codes and themes may emerge from the data. Adjustments to the coding schema are made as necessary to ensure that all relevant data are captured accurately and comprehensively.

5. Iterative Review
The coding and themes are continuously reviewed and refined to ensure they accurately represent the interview content. This iterative review helps in developing a deeper understanding of the data and ensures a thorough interpretation aligned with the research objectives.

6. Interpretation
The final step involves interpreting the coded data to extract meaningful insights and conclusions. This analysis directly addresses the research questions and captures the essence of the findings. The final output of the semi-structured interview is applying the real-life situation of green concrete in the Netherlands to the MLP framework.

3.2. Project Level: Multiple Cases Studies of Green Concrete Project

The study will conduct an in-depth qualitative analysis through three case studies to facilitate generalisation regarding the adoption of green concrete at the project level. These cases will be primarily examined through interviews, and the findings will be analysed using the cross-analysis method.

3.2.1. Case Selection

Defined Population

The infrastructure project managed by the demand side organisation is defined as the overall targeted population in this research. Furthermore, this research focuses on projects managed by Dutch government bodies, as they represent a significant proportion of national infrastructure projects and provide credibility to the generalisation of findings. To represent the overall population – several infrastructure projects within the Netherlands utilise green concrete during the execution process.

Selection Criteria for Cases:

Cases are selected using theoretical sampling as opposed to random sampling. Theoretical sampling enables the researcher to choose cases likely to yield rich and varied data that contribute to generalization. This approach prioritises understanding and theoretical insights about the phenomenon over the statistical representation of a broader population. The population was deliberately selected based on the author's judgment, which will likely yield rich and varied data contributing to generalisation. Criteria for this control include:

- Geographic Limitation: All cases are selected within the Netherlands to ensure uniformity in legal frameworks affecting procurement and contracting phases.
- organisational Scope: The selection is limited to government organisations to allow for consistent business processes represented in a standardized project management flow. In this case.
- Perspective: The examination of projects is exclusively from the client's perspective, such as Municipalities, Provinces, or Ministries. This focus aids in creating strategies tailored to the organisation's demands and facilitates an analysis of stakeholder management processes within public projects.
- Innovation Criterion: Cases include projects that incorporate green concrete innovations or conventional concrete usage. Various types of green concrete are considered, such as SCM, geopolymer concrete, and recycled aggregate concrete. The inclusion of conventional concrete cases allows for a reference point.

Following those selection methodologies, three cases are selected following certain requirements:

1. It should be under the jurisdiction of Dutch government entities.
2. The projects considered must have been active within the last five years.
3. They must serve public infrastructure needs.
4. Selection should be a post-procurement phase, with the main contractor already chosen.
5. There must be sustainability goals and evaluative measures within the project or program.

3.2.2. Case Description

Table 3.2: Overview of Cases

	Case A (HRP)	**Case B (QWR)**	**Case C (BPB)**
Project Description	Highway Renovation project	Quay wall renovation project	Bicycle pedestrian bridge
Role of Case	Reference point	Green concrete - Innovative project	Green concrete - Innovative project
Organisation level	Provincial	Provincial	Municipality
Project Scope	Large	Large	Small
Type of concrete	SCM CEM III	Geopolymer	Geopolymer, recycled aggregate
Project's phase	On-going construction	On-going construction	Completed (use of life)

Case A: Highway Renovation project (HRP)

This project is intended as the reference point in this research using conventional concrete (SCM) in the application. The main goal of this project is to improve road safety and flow between two municipalities in the Netherlands, focusing on intersection roads. It includes road repairs, lighting and signage updates, and expansions of certain lane road sections. Key developments include constructing a new roundabout and a bicycle tunnel in one area, developing a dedicated lane at the intersection, and reducing the number of road junctions to improve efficiency. In partnership with local authorities, the regional government oversees the project, striving to manage increasing traffic volumes and promote safer transport.

Figure 3.3: Example use of concrete in the road project

The project's overall plan is segmented into three primary stages. The first stage, which spans 2024-2025, includes the construction of a new underpass and roads. The second stage, expected to conclude in 2026, involves building another bicycle tunnel. The final stage, at the destination intersection, focuses on a new roundabout and bicycle tunnel, pending budget approval.

Currently, preliminary work for the first stage is ongoing, which includes establishing pedestrian crossings, updating cycling lane markings, and relocating utilities near city A. The underpass construction is starting to begin this year. The engineering consulting company leads the project's plan and control, with a single contractor for the initial phase. The selected contractor was recognised for its commitment to sustainability, cost-to-quality ratio, and minimisation of environmental and traffic disruption. A certain part of the project plans to use conventional concrete (SCM concrete) for the underpass. Due to the application of conventional concrete and other project characteristics, this project will be used as the reference point in this case study.

Case B: Quay Wall Renovation project (QWR)

This case was chosen to represent the regional-level public client organisation, the medium-high scale of the project, and the ongoing status, which is different from case C. This project aims to reduce the negative impacts of climate change and land subsidence in and around the city. Multiple public client organisations collaboratively manage the main scope, each overseeing different project components. One party is tasked with constructing the new pumping station, refurbishing the lock, developing a bank facility along the Canal, and maintaining the old sea dike.

Figure 3.4: Example use of concrete in Quay Wall (Personal communication, 2024)

Meanwhile, the selected client organisation is responsible for constructing a new bicycle bridge over the water and a dedicated cycle path along certain sections. The other party is charged with the construction of mooring facilities, a pedestrian bridge, and additional cycling paths. The involvement of multiple stakeholders adds a layer of complexity to the project.

Geopolymer concrete is utilised to construct the new bicycle bridge over the area and is managed by the regional public client organisation. A geopolymer concrete, developed in partnership with the university, will be used to rebuild an old quay wall panel near the new bridge. The sub-project is progressing through the detailed engineering design phase and mixture development and is preparing for construction.

Case C: Bicycle and Pedestrian Bridge Project (BPB)

This case was chosen to represent the municipal-level public client organisation, small-scale project, and completed project, differentiating from the green concrete application in case B. The project's primary aim was to replace the old wooden bridge in the urban area with a new concrete bridge. The wooden bridge had outlived its usefulness and was no longer fit for use due to rapid decay caused by the local climate—the replacement bridge measures around 20 meters in length and 3 meters in width. Managed by the local government, this project served as a trial for the possible expansion of similar structures throughout the city.

Figure 3.5: Example use of concrete in Pedestrian Bridge (Personal communication, 2024)

The project has been completed and has now entered the use of life period. During the procurement, the Municipality conducted market consultations, seeking interested and available local small to medium-sized construction firms. The contract followed a traditional format, awarding the work to the most economical bidder.

Green concrete, which is a combination of geopolymer concrete and recycled aggregate, was used to construct the main spans of the bridge. The implementation of green concrete is supported by multiple stakeholders, including researchers in the university provided the mixture design. Following the completion, the Municipality is now focusing on the long-term performance of the bridge, employing fibre optic technology for ongoing structural health monitoring.

3.2.3. Semi-structured interview

Criteria for Interviewee Selection Key criteria include selecting participants with diverse roles and experiences from each project, such as project managers, technical experts, contractors, sustainability, maintenance teams, and decision-makers directly involved in the projects. The interviewees should also represent a range of project stages, from initiation, design, tendering, and development to completion, providing a well-rounded analysis of the implementation of green concrete in the project.

Table 3.3: Interview of selected case studies interviewee

Case Study	Category	Actor code	Role	Date of Interview
1. HRP	Client organisation	HRP1	Project manager	30/April/2024
2. HRP	Client organisation	HRP2	Sr. Project leader	2/May/2024
3. HRP	Client organisation	HRP3	Sustainability advisor	29/April/2024
4. HRP	Engineering company	HRP4	Technical team	15/April/2024
5. HRP	Contractor	HRP5	Project Manager	10/May/2024
6. HRP	Client organisation	HRP6	Procurement	28/May/2024
7. QWR	Client organisation	QWR1	Technical team	11/April/2024
8. QWR	Client organisation	QWR2	Project leader	17/April/2024
9. QWR	Client organisation	QWR3	Asset team	12/April/2024
10. QWR	Client organisation	QWR4	Sustainability advisor	9/April/2024
11. QWR	Client organisation	QWR5	Sustainability advisor	18/April/2024
12. BPB	Client organisation	BPB1	Project Manager	22/April/2024
13. BPB	Contractor	BPB2	Project team	1/May/2024
14. BPB	Concrete producer	BPB3	Project team	26/April/2024

Interview Procedure

In general, the interview protocol followed the procedure in section 3.1.2. However, there is a differentiation in the interview content intended to understand the (sustainable) project management practices during the execution of the green concrete project. The interview content was divided into five parts.

I. Identified the concrete scope of the project
II. Identified enabler for green concrete implementation
III. recognised adjustments made during project phases
IV. Assessing barriers to green concrete implementation
V. Examining stakeholder reactions to green concrete innovations
VI. Recommended approaches for managing green concrete in the projects

In each part, follow-up questions were tailored following the relevant project phase and ongoing discussion findings.

3.2.4. Methodology of data analysis

After conducting the interview, the next method used the same procedure according to section 3.1.3. However, there was one adaptation for the codes and themes that follow the structure of interview contents, such as enabler, barrier, adjustment, stakeholder reaction, recommendation, etc.

The next step is conducting a cross-case analysis using three case studies. This method involves examining each case in relation to the others, identifying patterns, and noting differences and similarities.

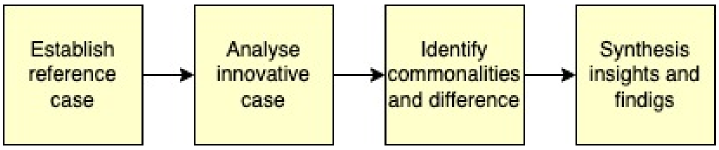

Figure 3.6: Workflow of data analysis

1. Establish the Reference Case
   The first step is to understand the reference case as a baseline for comparison. It should be analysed to establish a clear understanding of the context, processes, outcomes, and challenges within it. The reference case is the use of conventional concrete in construction projects.
2. Analyse Innovative Cases
   Each of the green concrete cases is then studied in detail. For these cases, focus on capturing unique or novel aspects that differentiate them from the reference case. This includes new methods, barriers, or enablers not present in the reference case.
3. Identify Commonalities and Differentiation Draw out common themes, strategies, and outcomes across all three cases, including the reference and green concrete cases. These commonalities might include shared challenges, similar organisational conditions, or overlapping strategies. In contrast, the differentiations focus on how the innovative cases differ from the reference cases. These differentiations could be due to various factors, such as the adoption of the new strategy, different stakeholder interactions, or barriers.
4. Synthesise Insights and Findings Synthesise the findings from the commonalities and differences to draw broader insights. This synthesis can help in forming conclusions about the effectiveness of certain strategies and the potential for replication of innovative project management practices observed in the innovative cases. Finally, compile the findings into a cohesive report.

3.3. Combining the Result: National and Project Level

A cross-level analysis was employed to conduct a triangulation method to consolidate and validate the research findings by integrating data from both macro and micro levels. This approach involves comparing the overall status of green transition in the Netherlands (national-level) with detailed insights from specific project case studies (micro-level). The objectives are to identify consistent patterns, recognise differentiation that may indicate policy gaps or implementation variations, and highlight unique outcomes from individual case studies.

Then, a comprehensive synthesis was developed, highlighting how national trends are reflected in or diverge from practical project-level implementations. This synthesis should also explore how project-level innovations or challenges could inform broader or higher strategies.

4

Findings (National Level): Green Concrete Transition in the Netherlands according to Multi-level Perspective (MLP) Framework

4.1. Landscape level

In general, respondents characterise the cement industry as a massive and high-volume sector. Furthermore, cement is seen as a stable industry and internationally organized market, relying on the same materials and practices for over a century. However, several disruptions are currently impacting this industry at the landscape level, including climate change policies, economic trends, changes in other industries, and research directions.

Policy Transformation: EU-ETS, Directive, and Structural Transition

Political and policy transformations play a significant role at this level. European Union's Emission Trading System (EU ETS) is perceived as the primary driver of the green concrete transition in European countries. Although various regulations aim to achieve emission reductions by 2030 and 2050, the EU ETS system directly impacts the cement industry. It sets a cap on the total amount of certain greenhouse gases that cement manufacturers can emit. Cement factories must acquire allowances for each ton of CO2 they emit, incentivising them to reduce emissions to avoid the costs of additional allowances. During interviews, cement manufacturers and associations noted that this system levels the playing field for all European cement producers and has effectively prompted the industry to reduce its emissions.

> **"So in Europe, the ETS system creates an incentive for the industry to move away from CO2 emission and to go to lower CO2 emissions and to carbon capture in the end. This creates a level playing field within Europe" - EXP7**

This system is further supported by the Carbon Border Adjustment Mechanism (CBAM), which imposes carbon taxation on cement imported from outside Europe. If the exporting country does not charge its producers for carbon emissions or charges less than the EU ETS, the importer must pay the difference to the EU. This policy also prevents the European cement industry from relocating factories to benefit from lower production costs. In conclusion, these mixed policies create directive and structural implications at the lower regime and niche levels, challenging them to reduce emissions.

Economic: Rising Trend of Carbon and Cement Prices

In addition to the EU-ETS policy, interviewees also highlighted the significant rise in carbon price trends over the past three years. Although the EU-ETS, combined with the CBAM, has already pressured cement producers, the current carbon price trends put additional pressure on them to make every effort to reduce emissions.

> **"So over the past years, you have seen that the price of cement has gone up, and most likely because of the increase in the price of CO2 and also the prices of energy, it's likely that this meant the price will go up further" - EXP6**

For instance, the carbon price in April 2020 was around 18 EUR, which increased to 73 EUR by May 2024. Respondents anticipate that prices will continue to rise in the coming years. This situation not only motivates the cement industry to adopt incremental innovations such as low-carbon clinker or alternative SCMs but also encourages investment in costly technologies for reducing emissions, such as carbon capture utilisation and storage (CCUS), which require substantial funding. The savings on CO2 prices could be comparable to the cost of this equipment. Moreover, respondents emphasised that cement prices have also increased over the past five years due to these upward trends.

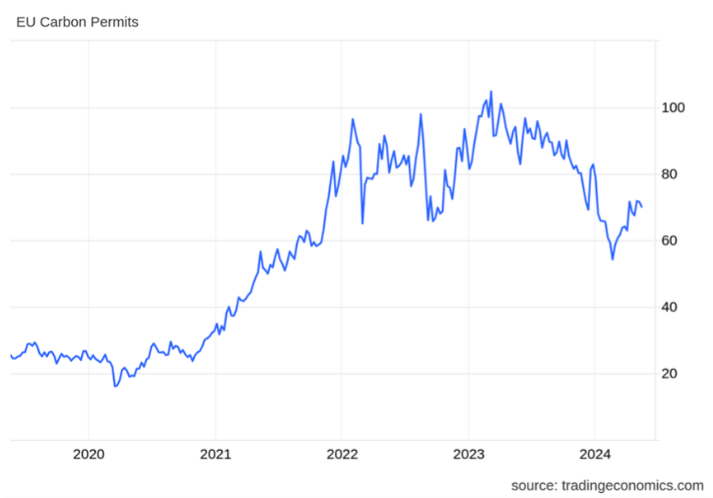

Figure 4.1: EU Carbon Price over past five years (Economics, 2024)

Interrelation sector: Change in steel industry

Beyond policy and regulatory factors, changes in the industry landscape also pressure the cement industry. Currently, Most cement factories in some European countries use slag, a by-product of traditional iron-making processes, as a main SCMs. However, as steel producers shift to Direct Reduced Iron (DRI) technology, which does not produce such by-products, this transition could lead to a scarcity of blast furnace slag, a critical low-cost, low-carbon SCM in cement production. This shift could significantly impact regimes or countries that have benefited from using slag as their main SCM to reduce emissions significantly. According to respondents, this change in the steel industry could threaten the current excellent carbon footprint records of several countries. Conversely, this situation also incentivizes cement factories to research alternative SCMs and invest more in technological research to replace the current slag.

> **"And slag is a unique product. There is no alternative material that comes close to the properties of slag, so we need to make concessions.." - EXP6**

Technical: Bulk Industry of Cement

Annually, the global output of cement is around 4 billion tons, underscoring its massive scale and significant role in worldwide construction. Interview responses highlight a critical issue: the success of sustainable innovations in the concrete and cement industry heavily depends on the availability and scalability of alternative raw materials. Any further innovations must consider this nature of cement if they want to be the mainstream in this sector. If these innovations cannot economically access or sustain the required volume of alternative materials, their market viability significantly decreases.

> **"It was mostly about the realism; the nature of our industry is that we are a bulk industry. So, we're talking about huge volumes... Also, in the Netherlands, we have a cement market of, let's say, around about 4 to 5 million tons each year.. of course, we need a substantial volume of raw materials." - EXP6**

This industry's nature also guides innovation and changes in the system below this level, considering this aspect as one of the main criteria for specific innovation development. Additionally, other factors related to the industry's bulk character create further challenges for innovation, such as high energy consumption and extensive supply chain infrastructure.

Table 4.1: Findings of Enabler of Change in Landscape Level of Cement Industry

Enabler of change	Context	Socio-technical dimension	Impacted regime/niche
EU - ETS	European	Political transformation	Cement manufacturer
Rise trend of carbon price	European	Economical	Cement manufacturer and CCUS innovation
Change in steel industry	Worldwide	Cross-sector interaction	Slag base SCM cement producer, SCM and Geopolymer innovation (niche)
Bulk Industry of Cement	Worldwide	Market	Cement manufacturer and niche innovations

4.2. Regime Level

In the Netherlands, the development of green concrete is considerably more advanced compared to neighbouring countries such as Germany and France and well ahead of the global average. This advancement is largely due to the widespread use of SCMs-CEM III cement, which contains only about 50% of the clinker compared to the global average of 75%. The Dutch market is recognised as a frontrunner in this sector. Over the past decades, incumbent cement producers have successfully introduced these products into the Dutch concrete market, where they have become well-established because of the high-quality slag available from steel producers in Ijmuiden and Rotterdam.

> **"I think the concrete in the Netherlands is amongst the most sustainable in the world. We have a clinker content only of about 50%; the other half is blast furnace slag... And if you look for substituting your clinker, I think the Netherlands is way ahead" - EXP4**

The Netherlands' country-specific factor also elevates the importance of sustainability and climate change on the national agenda. The country's vulnerability to rising sea levels, lack of resources for quarrying cement, and limited land for landfilling emphasise the need for emission reduction and recycled materials. Consequently, many cement manufacturers consider the Netherlands an ideal testing ground for innovations in green concrete, supported by a highly educated population and heightened awareness of sustainability issues. Over the past four years, the discourse on sustainability within the concrete industry has rapidly evolved. Previously taboo topics like CO2 reduction and circularity are now mainstream subjects at concrete seminars and discussions within the country.

> **"So if you were three or four years ago, if you were on a concrete day and used the word sustainable, you would be kicked out. Now everybody talks about, and all presentations are about sustainability" - EXP7**

Incumbent in the regime level

SCMs cement is viewed as an incumbent within the Dutch concrete sector, interacting effectively with other socio-technical systems. Current regulations and standards recognise SCMs cement for its mechanical properties, strength, and durability. Moreover, SCMs cement is culturally perceived as maintaining the inherent safety and reliability of traditional concrete products. The main cement producers in the Netherlands offer SCM CEM I, CEM II, and CEM III products, with only about 20% of the market still using CEM I, which has the highest clinker content. Currently, there is a high effort within the industry to shift from CEM I to CEM II to further reduce emissions.

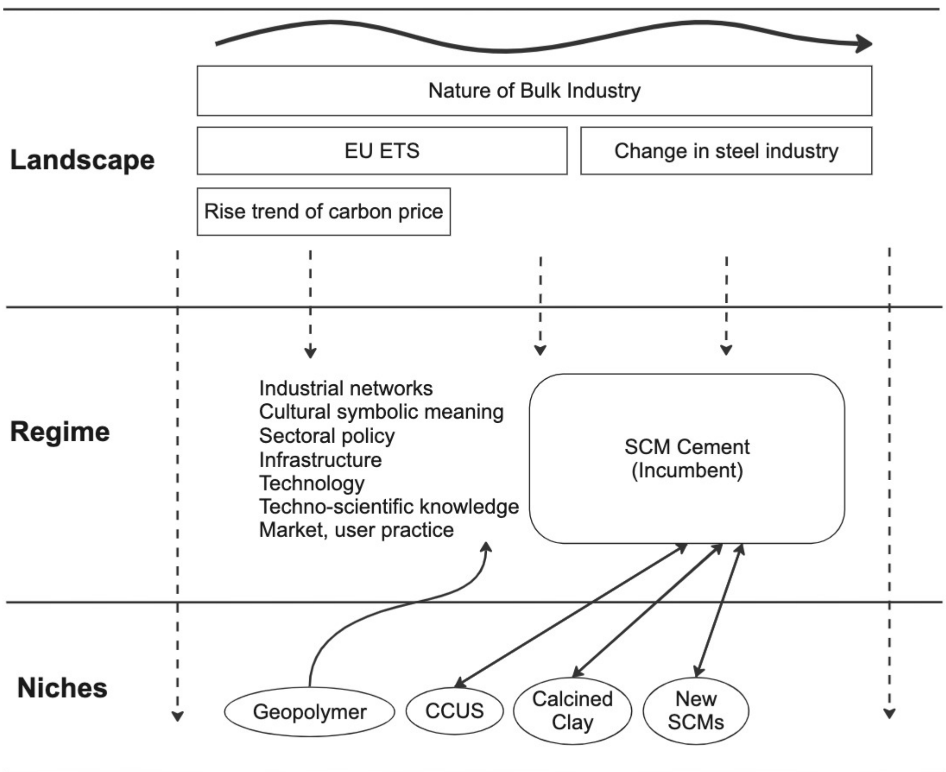

Figure 4.2: Green Concrete Transition in the Netherlands Described in MLP Framework

Despite its dominance, the SCM cement sector faces significant pressures from the landscape level, including pressures from the EU's carbon tax scheme (EU ETS) and technological changes in the steel industry, which threaten the availability of slag due to shifts towards direct reduced iron (DRI) processes. The incumbent responds to the challenges through two approaches: incremental and radical transformation. In response to incremental changes, cement manufacturers are investing in research to find suitable alternative materials such as calcined clays and volcanic ashes. They are also increasing the use of alternative fuels, aiming to boost their share from 70% to 80-90% of total energy used. These initiatives are well-supported by cement producers as they prepare to meet emission targets and address the potential scarcity of slag. On the other hand, for the radical change and addressing long-term CO2 reduction pressures, there is significant investment in CCUS, which would be compatible with existing infrastructure.

> **"So we're working in parallel on all the different options. The carbon storage is the most expensive one. It will be the last one and only for the unavoidable CO2 remaining" -EXP6**

Potential new entrant

In contrast, geopolymer concrete is trying to break out to the regime level. However, it has yet to gain favour with incumbents and the market because it utilizes the same materials, such as slag, challenges related to the technical performance in structural applications, scalability, and safety. Currently, there is only one commercial supplier of geopolymer concrete, which struggles in the market due to those limitations.

> **"Now we are almost the only company supplying geopolymer concrete. But there, it's strange to say, but there should be more. Then we can gain volume and mass.." - EXP9**

All combination and possibilities

In conclusion, most respondents agree that achieving carbon reduction targets by 2030 and 2050 will require a combination of all possible green concrete alternatives, as no single solution is statistically sufficient to meet these goals, particularly due to the unique properties of slag. Additionally, it is recommended to remain open to any potential innovations, even those that may seem far-fetched today. Experts also suggest learning from other transitional examples, such as electric cars. The nature of such transitions can be described analogously by the S-curve, which requires a considerable amount of time to reach the acceleration point. However, once this point is reached, the transition speed increases exponentially.

> **"Don't pick one. Pick them all. There's no silver bullet. Of course, SCMs are very important. Whether the SCM is used in geopolymer or as a substitute for Portland cement. That's not the most important thing. The most important thing is scaling material other than slag and fly ash.."- EXP6**

The following sections will explain the socio-technical findings at the regime level in the Netherlands, categorised by industrial networks, sectoral policies, market and user practices, cultural symbolic meanings, and technology developments.

Table 4.2: Findings of Possible Transition Pathways in Dutch Concrete Sector

Pathways	Transition process	Mechanism
Breakout mechanism (1)	New SCM alternatives (calcined clays, volcanic ashes, bottom ash) and/or cutting-edge CCUS technologies have become viable in the market and are successfully implemented by existing cement manufacturers.	Bottom-up
Breakout mechanism (2)	Geopolymer concrete has matured and successfully secured a certain portion of the concrete market in the country (regime level)	Bottom-up
Transformation (1)	The incumbent cement company endorses the pilot project and development for the new SCMs alternatives, integrating them successfully with the existing manufacturing facilities. These new SCM alternatives meet the target for carbon reduction	Top-down
Transformation (2)	The incumbent cement company backs the pilot project and development of new SCM alternatives and CCUS, which are successfully integrated into the existing facilities. However, the performance of these new SCM alternatives falls short of achieving the carbon reduction target. Further reductions in residual carbon from CCUS are needed due to the inevitable presence of clinker.	Top-down / Internal layer
Reconfiguration	Certain companies specialising in CCUS technologies (shared technology with other sectors) have matured in technical and economic feasibility. Cement manufacturers are creating joint ventures with these CCUS companies to provide low-carbon cement to the market.	Bottom-up
Substitution	New types of cement utilising calcined clays, bottom ashes, or volcanic ashes as SCMs are challenging the current dominance of slag-based SCM cement producers. This shift is changing the shape of the country's cement market.	Bottom-up

4.2.1. Industrial Networks

The industrial networks among concrete stakeholders in the Netherlands are structurally interconnected through various organisational levels and agreements. Nationally, since 2018, the connection between concrete and cement stakeholders has been formalized by the Betonakkoord, or Concrete Agreement, which aims to achieve emission reductions by 2030 and 2050. This agreement facilitates collaboration between public client organisations, concrete producers, cement manufacturers, cement associations, contractors, and engineering consulting firms. However, forming this agreement was a complicated process, as each party had differing interests. Initially, some participants seemed primarily interested in gathering information for commercial purposes.

> **“Some companies would only like to hear what other people were working on and not give information by themselves. That was very tough.”- EXP3**

Locally and regionally, an initiative known as Bouwcirculair links stakeholders through nodes or concrete chains (e.g., Betonketen Amsterdam or Betonketen Zuid-Holland) that connect partners within a specific radius to leverage locational advantages for promoting circularity and reducing carbon emissions. Moreover, the Dutch concrete industry supports the Beton Innovatie Loket or Concrete Innovation Desk, an independent entity primarily tasked with verifying new innovations in concrete or cement. In addition, a coalition of concrete buyers from municipalities and provinces, known as Pianoobeton, exists, facilitating the sharing of knowledge regarding the purchasing processes for specific thematic areas related to concrete. However, this coalition has yet to prove effective in promoting the adoption of green concrete. On a project level, various arrangements for demonstration or experimentation projects using green concrete, such as geopolymer and alternative SCMs, are mainly sponsored by frontrunners in public client organisations.

Dysfunctionality of networks

Despite these efforts, some experts within the industrial relations network believe the movement toward sustainable concrete, especially for meeting the 2030 targets of the Concrete Agreement, is insufficiently fast.

> **“As long as there is now no penalty in the concrete or in the agreement, it doesn’t make much difference. It’s much more about willingness as a company or public entity to be part of this development” - EXP8**

Interviews roughly revealed that only about 15% of the market is actively working toward sustainable concrete practices, while the remaining 85% are delaying action. This calls for a metaphorical ”switch button” to motivate the rest of the market toward green concrete. The Concrete Agreement is viewed as a voluntary initiative without penalties, relying on the willingness of each party to participate. Although an example of successful collaborations exists in the past, such as the Dutch polder system, these cooperative efforts have not been as effective in this context.

> **“At the same time, we have some sort of reputation for sharing things and doing things together as the classical Dutch polder system. But in this case, it is not really working to my satisfaction. I would say that I’m actually even part of it, myself” - EXP8**

In addition, some experts note a decline in the effectiveness of knowledge collaboration within the Dutch concrete sector, which previously succeeded in introducing innovations like self-compacting concrete. Currently, barriers to innovation are becoming more pronounced due to organisational and commercial constraints.

4.2.2. Technology

New Supplementary Cementitious Materials (SCMs)

In the Netherlands, although slag-based SCMs currently predominate in the cement and concrete market, extensive research and development efforts are focusing on alternative green concrete solutions.

In the near term, the primary focus of both incumbent cement manufacturers and other stakeholders is to search for suitable SCM alternatives for replacing slag. Interviews with multiple parties within the concrete industry highlight calcined clays and volcanic ashes as the primary subjects of this research due to their scalability and technical feasibility. Efforts to create low-carbon clinker involve developing alternative SCMs derived from calcined clays. This method aims to replace traditional limestone in kilns with clays that emit less carbon, thereby optimising the calcination processes integral to cement production. Additionally, volcanic ashes, recognised for their similar properties to natural cement but with fewer environmental impacts, are considered another promising alternative. These ashes, which can be sourced from places like Germany and the Mediterranean, could also be supplemented by using bottom ashes from the 10-12 incinerators operating in the Netherlands.

> **“I think in 10 years, we need to be able to have 2 million tons of other SCM, and that will mostly be calcined clay and volcanic ash” - EXP7**

Other potential SCM alternatives discussed include natural pozzolan and finely recycled materials. Most interviewees are optimistic that all those alternatives will dominate the market within the next 10-15 years in the Netherlands. They perceive technically no significant barriers to development, though extensive testing, such as for carbonation, is required and can be time-consuming. Presently, the relatively low cost of slag—at around 130 euros per ton—poses a challenge to the economic feasibility of developing these alternative SCMs. However, experts anticipate that rising demand for SCM from neighbouring countries like Germany and France will drive up slag prices. Should slag prices surpass those of OPC, which is recently around 200 euros per ton, the development of alternative SCMs would become markedly more appealing.

Carbon Capture Utilisation and Storage (CCUS)

In the long-term strategic transition, cement manufacturers are increasingly focused on developing CCUS This technology is favoured by most manufacturers as it can integrate with existing infrastructure. Despite extensive efforts to reduce emissions from clinking, a residual amount of carbon remains, making this technology crucial for achieving the zero-emission target by 2050. Consequently, industry leaders consider CCUS unavoidable. They also express concerns that prioritising carbon capture might disincentivise the development of new cement, such as alternative SCMs and geopolymer, which address emissions at the “front of the pipe”.

> **“And finally, there is the carbon capture option. This is very expensive, but in the long run, it’s cheaper to capture the CO2 than to emit and to pay for the emission rights” - EXP6**

However, experts recommend maintaining openness to the potential of CCUS, emphasising that any initiative aimed at preventing carbon release into the atmosphere is beneficial. During the discussions, CCUS was categorised into three levels—good, better, and best—based on its application and effectiveness. The first category includes technologies that capture carbon and store it in locations like depleted oil fields. The second approach involves capturing carbon and converting it into stable minerals, such as magnesium carbonate, by injecting it into naturally occurring olivine, which can then be utilised as concrete or pavement. However, the availability of olivine is limited. Lastly, the best method, developed by companies like Paeble (a Dutch and Norwegian collaboration), involves injecting carbon into silica-rich dust derived from crushed concrete. This is considered sustainable due to the infinite availability of demolition materials.

> **“And then you have the best solution, which is a circular solution for a linear problem. That’s the best. So there are all kinds of CCUS and I grade them on good, better, best”- EXP7**

The most recent advancements indicate that a pilot project for CCUS is expected to be operational by the end of 2024 in Norway, which comes from the same company that has the vast majority of the cement market in the Netherlands. This project represents a significant step towards scalable, practical solutions for carbon management in the cement industry.

Geopolymer Concrete

Lastly, many stakeholders and experts currently view geopolymers as not yet sufficiently developed for mainstream use, particularly at the regime level. Interviews with cement manufacturers and concrete associations have revealed that geopolymers are not a priority or an option in their agendas. This is partly because this alternative cement heavily relies on slag, a material already utilised in SCMs.

> **"It's a young child. In terms of maturity, it can do things. But there's still a lot to learn before it gets adult. But several nice things are done with geopolymer" - EXP7**

While geopolymers do offer reductions in carbon emissions through material substitution, they may not provide environmental gain. In addition, they face significant technical challenges, including the technical performance of geopolymer concrete, which is not yet adequate for structural applications, such as durability and resistance to frost and thaw cycles. Despite many good signs in the development of geopolymer concrete, utilising non-slag materials remains challenging.

Experts recommend gradually adjusting the composition of geopolymers by incrementally increasing the proportion of volcanic ashes or other material compared to slag, for instance, starting with mixtures like 10:90, then 20:80, and so on. However, the future of geopolymers looks promising. Currently, in the Dutch market, SQAPE is one producer of geopolymers that has commercialised its products at the regime level, with verification provided by the Beton Innovatie Loket.

> **"It's not so that Geopolymer will take over the concrete industry. It will take apart, and many other technologies will also take part" - EXP9**

However, this product currently faces several challenges in the market. These include price competitiveness and risk-averse purchasers who are hesitant to adopt new technologies. Many stakeholders predict that geopolymers will eventually find certain parts in the Dutch concrete market, especially those that do not require high load-bearing capacity or pose significant risk.

4.2.3. Sectoral Policy

In general, many concrete stakeholders believe that policy harmonisation between higher and lower levels is quite collaborative. At the landscape or European level, the EU ETS system incentivises suppliers, particularly cement producers, to minimise their emissions. In contrast, during the tendering process, particularly within public client organisations such as provinces or municipalities, the milieukostenindicator (MKI), the Environmental Cost Indicator, provides an advantage to bid proposals that support CO2 reduction. This mechanism levels the playing field at the project level. Although the MKI does not directly push contractors to use green concrete, it does assign significant weight to carbon reduction during tendering, potentially encouraging the use of low-carbon concrete in projects. This tool is seen as beneficial for aiding the transition to green concrete.

> **"What we most likely do is prescribe MKI as low as needed to make this alternative feasible" - EXP8**

Experts also recommend developing standardisation measures similar to MilieuPrestatie Gebouwen (MPG), Building Performance Indicator, which displays CO2 emissions per square meter of building. In building standards, there is a maximum acceptable CO2 emission level; however, similar standards for acceptance are not established for other types of infrastructure, such as bridges, roads, or other facilities. This standard should also apply to other infrastructures to show carbon emissions per unit. Moreover, building codes and standards are perceived as prescriptive, discouraging contractors from using sustainable concrete due to the additional testing required to achieve equivalency with traditional materials. Additionally, innovators in SCMs highlight the lack of legislation concerning cementitious materials. They face lengthy processes of compiling reports and conducting testing to prove the performance of cementitious concrete.

Furthermore, experts also advise that the Dutch concrete sector should prepare for potential future legislation that might restrict concrete infrastructure development due to limited carbon emission quotas. This would be similar to previous restrictions placed on nitrogen emissions in the Dutch farming industry. However, the Dutch government is expected to employ different methods to achieve these targets in the future.

> **“That’s like we like what we do with the farmers. We have asked them 20 years to reduce the emission of nitrogen. We asked them 20 years to do it, but they didn’t, and now we say, OK, 50% of the farmers need to stop because we need to reduce..” - EXP7**

4.2.4. Market Dynamics and User Practices

Presence of front-runner and risk-averse purchaser From the perspective of demand, interviews reveal diverse responses from public clients toward sustainable concrete. On one hand, many parties prefer to adopt new solutions only once they have reached a significant level of maturity due to a risk-averse attitude. Typically, public client organisations in the Netherlands depend on the Technological Readiness Level (TRL) scale, preferring technologies that achieve levels 8 or 9. On the other hand, some market segments are keen to engage in experimental programs such as Rijswaterstraat, Prorail, and some municipalities and provinces have been identified as the frontrunners by the respondents. These groups tend to apply sustainable concrete in low-risk situations, such as in non-load-bearing or removable parts.

> **“So you see some resistance in the market, and they want to remain with what they know now instead of switching to. it’s not for all the market but for most of the markets.” - EXP6**

The interviews also highlighted that the level of expertise among in-house engineers significantly influences how organisations respond to sustainable concrete options. On the other hand, current cement producers and concrete associations note a lack of structured purchasing and demand in the market, which does not sufficiently motivate cement manufacturers toward specific innovation directions. Furthermore, another cement producer pointed out the absence of standardised demands across organisations, with each requesting different solutions, complicating the ability to meet a minimum business case. This lack of standardisation and adequate demand forms a significant barrier for suppliers in the Netherlands.

Concrete buyer groups have suggested forming a coalition of small and medium-sized purchasing organisations to consolidate demand for specific green concrete solutions, particularly the solution nearing maturity. Additionally, technical methodologies are suggested to catalyse a broader adoption among organisations, such as over 300 municipalities in the Netherlands, which could create higher aggregate demand than Rijkswaterstraat or Prorail. One suggestion is to establish a standardised labelling system for concrete products—such as grades B, A, and A+—that denotes durability performance, maximum carbon emissions, environmental class, and circularity level, aiding client organisations in making informed purchases. This labelling system could help small purchase organisations move forward, particularly since they depend on higher purchasing rules.

> **“Every governmental organisation has its own agenda. And so their own priorities and questions. If you can make that more uniform request. it is easier for the industry to adapt to the question now that I have to adapt to every single” - EXP9**

No one fits all concept

Addressing user practices, experts emphasise the future scarcity of slag—a key cementitious material in SCMs-CEM III in the Netherlands—and recommend preparing the market for a new paradigm in cement usage. Historically, the market has been accustomed to a ’one cement fits all’ approach. This needs to shift towards a ’cement with purpose’ strategy, where different types of cement are developed for specific applications, each with varying strengths, curing times, and durability profiles. This shift is essential for saving the emissions quota and addressing the challenges of replacing slag.

> **“When you go to the shop to buy CEM I and use it in your garden to make something, I think it’s really sick. That’s so much pollution. You don’t need that in the garden, while you need it for building a bridge” - EXP3**

4.2.5. Cultural Symbolic Meaning

In the cultural and social spheres, the regime level reveals dynamic shifts toward adopting green concrete. Initially, the cement industry in the Netherlands tended to maintain the sacred view of concrete as a highly durable and safe material. During interviews, many experts noted that there is no other structural material comparable to concrete in terms of longevity and durability, capable of lasting for decades or even centuries. This resilience is often celebrated, and many stakeholders are keen on preserving this legacy.

However, the introduction of sustainable concrete has challenged these perceptions, particularly regarding the material's inherent strength. This shift can potentially reduce concrete's reputation for robustness. Such changes are viewed symbolically among stakeholders, where the strength of concrete represents more than just a physical property; it embodies reliability and security. This symbolic value resembled when one Dutch cement supplier attempted to transition from SCMs-CEM I to CEM II, which led to a perceived reduction in strength and, subsequently, customer resistance, driving to buy from its competitors.

> **"Concrete is a very durable material. So it has a lifespan of possibly, depending on the situation, 50 years to infinite, like the Pantheon, which is 2000 years old. So that's kind of infinite, and so that's very valuable to keep it that way" - EXP7**

Additionally, another practitioner highlighted the solid knowledge and stability of the concrete industry, which has relied on traditional materials like cement for over 80 years. The current focus on carbon emission reduction presents good momentum for the industry to explore alternative materials beyond traditional cement. This period of transition is not just about technological innovation but also cultural adaptation. Moreover, societal attitudes towards risk tolerance have shifted. Historically, there was greater acceptance of potential failures; today, there is less tolerance for risk, which poses a significant cultural barrier to adopting new materials in concrete formulations.

4.2.6. Techno-scientific knowledge

During the interviews, many respondents highlighted the superior qualities of slag as a SCM predominantly used in the cement market. They noted slag's unique characteristics, which are currently irreplaceable by any single material under research, such as calcined clays, volcanic ashes, and bottom ashes. To achieve performance comparable to that of current slag-based products, a configuration or combination of several alternative materials will be necessary. Researchers anticipate that future SCM cement formulations will involve more complex chemical interactions. Furthermore, cement manufacturers noted the high quality of slag used at the cement factories in Rotterdam and Ijmuiden, classifying it as superior.

> **"So there will be more chemistry in the concrete than before to optimise the properties, and in the past, the properties were all determined by the cement" - EXP9**

Additionally, a significant technical challenge identified in the Netherlands concerns the use of cement in the precast industry. While respondents generally did not perceive significant issues with the application of low-carbon cement or concrete in ready-mix concrete, they highlighted substantial barriers in the precast sector. This sector requires concrete with a rapid strength development time to maintain daily production cycles that optimise the use of space and materials, such as moulds and formwork. Low-carbon cements like SCM-CEM III, which contain less clinker, typically require longer times to reach full strength, posing challenges for industries needing quick turnaround times.

> **“There’s no problem. I have sufficient space. So I simply make some extra moulds so I can leave them a day over athen so there are two days instead of 16 hours or whatever, and then okay, so we did all kinds of tests, and they went very well. He was very happy, and then suddenly he called me. He said, ”I have to stop by. I’ve actual work. So I need the space. I need the 16 hours back.” So that’s real life”- EXP5**

Therefore, respondents suggested exploring alternative approaches to reduce emissions specifically tailored to the precast industry’s needs.

Table 4.3: Socio-technical Aspects and Findings (1)

Socio-technical aspects	Findings (Codes)	Frequency
Industrial networks	A concrete agreement among stakeholders in the Netherlands is not yet effectively driving the majority of the market due to the absence of sanctions and voluntary basis.	1
	There are several coalition initiatives such as Bouwcirculair, Pianoobeton, but they are not effectively stopping the procrastination in the market.	2
	Good cooperative efforts in the past, such as the “Dutch polder system” or “development self-compacting concrete,” have not been as effective in this context due to organisational and commercial barriers.	2
	Pessimism about meeting the 2030 target, yet optimism for 2050 among concrete stakeholders	5
	The majority of the concrete sector generally requires a ”switch button” to initiate sustainability actions	3
Technology	Volcanic and calcined clays are viewed as the most promising solutions for new SCMs in the near future	2
	The current low price of slag is seen as a deterrent to the development of new SCMs	2
	Demand from neighbouring countries could boost slag prices and stimulate SCMs innovation	2
	Cement producers are working in CCUS for long term target	4
	CCUS could be seen as ”good, better, and best” instead of being sceptical	1
	It is recommended to change from slag-based geopolymer concrete to other materials incrementally	1
	Geopolymer is not currently on the agenda of cement producers	5
	There is a verified single geopolymer supplier struggling in the Dutch market	1
Sectoral policy	MKI is a primary motivator in the tendering process	3
	There is a suggestion to create MPG for other infrastructures	2
	There is anticipation of future policies that may reduce construction (similar to the Dutch agricultural sector)	2
	The legislative process for new SCMs is lengthy due to the testing process.	1

Table 4.4: Socio-technical Aspects and Findings (2)

Socio-technical aspects	Findings (Codes)	Frequency
Market dynamic, user practice	There are presents of frontrunners and risk-averse purchaser side	5
	TRL is used to assess maturity innovation by purchaser	2
	There is no consolidated demand sufficient to support a business case certain innovation in supplier	3
	Each client has unique demands (lack of standardization)	1
	There are suggestions to introduce labelling for concrete products, especially for drivers to the majority of the market	3
	There are suggestions to move from a ”one-size-fits-all” approach to ”cement with purpose.”	3
Cultural symbolic meaning	Concrete is traditionally viewed as a safe material	1
	Green concrete is seen as potentially disrupting the sacred view of concrete	1
	Time to learn and accept new practices, new material for the concrete sector after being established for century	2
	There is currently less tolerance for failure than in the past.	1
Techno-scientific knowledge	The superiority of slag is recognised, making it hard to replace with any single new SCM	3
	SCM will become more chemically complex in the future	4
	The Netherlands benefits from high-quality and high-quantity slag from steel factories	2
	Changes in the precast industry are expected to be complex.	1

4.3. Niche Level

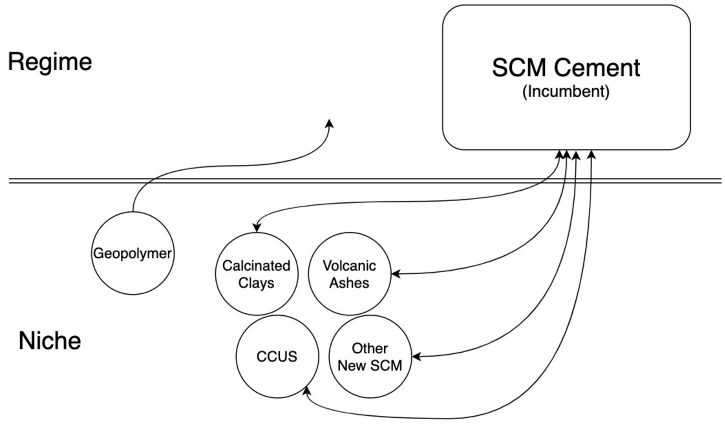

Figure 4.3: Niche Level of Green Concrete Transition in the Netherlands

Generally, respondents believe that the Netherlands offers a conducive environment for developing niche innovations due to country-specific factors. Currently, many radical innovations are sponsored by public client organisations in the Netherlands. For example, geopolymer concrete is frequently supported for its potential to completely 100% replace traditional cement.

> **"We think and also international materials companies look upon the Netherlands as a large field lab to develop more sustainable alternatives since we have a smaller market. I think we allow new solutions. We have highly educated people.." - EXP8**

This radical innovation is typically protected from standard market pressures through various methods. For instance, client organisations often adopt unique tendering approaches and allocate higher budgets to these projects. Next, as a risk mitigation strategy, these projects are usually implemented in low-risk environments with no high-load requirements, such as pedestrian bridges. Moreover, extensive testing is conducted at the initial stages of mixture formulation to ensure compliance with existing codes and standards. The Beton Innovation Loket, an independent certification body, is utilised to verify the material's performance. Finally, to further protect against durability risks, monitoring systems are installed post-construction, often involving third-party organisations like TNO. The frontrunners make those example strategies to protect it from the current socio-technical system in the Netherlands.

> **"Society presumes that we have a lot of experience with concrete, and it is OK, but still, after using it for 150 years, not everything is known. And I almost dare to say that we know more of the geopolymer concrete mixture we apply in our constructions" - EXP2**

However, many experts said that the geopolymer required to address several challenges before it would break out to the regime level, including heavy dependence on slag, scalability of alkali activators, higher costs, technical performance for structural applications, and safety concerns during construction.

Moreover, the Netherlands also hosts various other radical innovations in green concrete, including electric truck mixers, the development of alternative SCMs from volcanic ashes and calcined clays, and advancements in carbon capture utilisation of minerals. Those innovations indicate that the Netherlands is a fertile ground resembling variation and evolution characteristics that are necessary at this level. Some respondents argued that some innovations have advantages as they can be adopted and sponsored by the current infrastructure of incumbents, such as mentioned above. In contrast, some innovations are identified as the independent niche, such as geopolymer concrete, since that is not part of the cement producer agenda.

> **"So the entire industry, and it's for the whole building industry. It's now time to learn to accept new materials because, for the last 150 years, we have only used cement-based concrete and steel reinforcements" - EXP2**

In discussions about the interactions between various niche innovations, buyer groups acknowledge that while these innovations are often fragmented across different public client organisations in the country, there is potential for improvement, such as developing a shared knowledge roadmap. Nevertheless, some experts also view the separate initiatives as beneficial, arguing that they help preserve the survival of innovations since the failure of one does not heavily impact others. Currently, no innovation at the niche level is considered a failure, as the concrete is still in the early stages of transition.

> **"But most technology, you see, there are a few parties that get most, and that's an ecological thing. If you look at the forest in it, like a rainforest. There are a million species of trees, and 80% of the biomass is in one, two, or three types of tree. You also see this in nature. It's humans take 90% of the resources on Earth, and the trees in it look to go to the Amazon, and you see the big trees. The big trees are one or two species, and they take 80% of the biomass, so they take 80% of the energy. Something's worked. Some things don't. It's good that they are independent of each other, and If there were only one, it would be the chances of success would be very low" - EXP7**

5

Findings (Project Level): Green Concrete Case Studies in the Project Level

5.1. Case A: Highway Renovation Project (HRP)

5.1.1. Organisational Response to Sustainable Innovations

In this regional organisation, a principal driver for incorporating sustainability, which aims to reduce CO2 emissions and promote circularity, is driven by the 2030 and 2050 targets set by the national governmental agency. However, most respondents perceive that these high-level policies lack a connection to practical, operational levels. While the government recognises the urgency to reduce emissions in construction projects, most respondents point out the absence of specific, tangible targets for implementing this vision at the project level. For instance, the organisation has not yet developed measurable Key Performance Indicators (KPIs) for the percentage of construction projects that achieve reductions in CO2 emissions. Furthermore, both sustainability advisors and project teams agree that translating high-level policies into concrete targets for construction projects is difficult.

> **"Apparently, it is possible to have all kinds of goals that you have to work on a high level, and on the other hand, there is no obligation in the project to work with those goals. So there is a split between those two levels, the operational level, and a strategic level, and it is very hard to get these levels to meet" -HRP3**

Currently, the sustainability department within the organisation is working to bridge these gaps between policy and practice. So, adopting sustainability innovations, such as green concrete, often depends on the personal interest or motivation of project leaders. Despite this, respondents have noted an improvement in sustainability awareness among organisation workers over the past two years, although they believe the progress is not happening quickly enough.

> **"So if something should be reconstructed or built, it is up to the project leader whether he gets his information from this sustainability team or not. That depends on the scope of this project and his own intrinsic motivation." - HRP3**

In addition, within the organisation, due to the nature of highway projects, respondents identify other priorities that may compete with sustainability efforts, such as safety and maintenance. Given the critical need to prioritise road user safety, radical innovations in concrete could potentially conflict with that interest. Furthermore, minimising disruptions during road maintenance is another significant concern; thus, the durability of applied products is crucial to avoid future disruptions to road users. Finally, the current overdue maintenance status in many provincial locations is also seen as a barrier to adopting radical innovations within this client organisation.

The advisor also emphasises the importance of discussing sustainability innovation as early as possible in the project phase. The more advanced the project progresses, the less room for innovation to be applied. Moreover, another respondent suggests the need for effective communication and the ability to influence people since, currently, sustainability innovation is mainly about people and not a system.

5.1.2. Design and Tendering Phases

Historically, this project has experienced a long delay, extending from the initial planning in 2013 to the actual execution stage in 2023. The project employs a functional specification design that outlines only generic goals for the highway without asking for specific technical details. Consequently, this approach does not mandate any specific sustainability innovations for the contractor. In designing the project, the client organisation has engaged external engineering consultancy firms to assist with preparing tender documents. Moreover, these services extend to support during both the tendering and construction phases. Generally, respondents indicate that the organisation lacks sufficient in-house engineering expertise to manage the planning and control processes. This deficiency is seen as a significant barrier to implementing innovation within the project, as the knowledge predominantly stays within the external engineering firms. Additionally, the dynamic turnover of these consultancy relationships often leads to a loss of expertise for the client organisation. Although the project is executed in collaboration with third-party entities, respondents suggest that the client should be capable of capturing relevant market knowledge.

> **“We also have to hire external consultants to look into that, and that’s all right. But a great disadvantage of that is that when these people go again because they’re not interpersonal, you lose that knowledge again. So it’s a really a stream of knowledge in-out that you can’t hold it in your organisation” - HRP1**

Respondents also mentioned that the MKI is utilised to assess the carbon footprint of bidder proposals. Besides the MKI, other factors such as communication plans, disturbance reduction plans, and pricing are also considered when evaluating contractor performance during the tendering phase. Thus, the MKI serves as the primary driver of sustainable innovation within the project. However, due to this rule, contractors might adopt strategies that deproritise sustainability to focus more intensively on other aspects, such as reducing costs significantly to win the tender. This could also trap the market in using conventional methods and materials during construction so that sustainability would depend on each contractor’s strategy. Consequently, CO2 emission reduction is not consistently proritised.

> **“OK, we will not be sustainable at all, but we’re going to try to offer a very low price, and they can also win the tender” - HRP1**

Furthermore, in interviews with advisors, it is noted that current purchasing regulations do not mandate sustainability. There is a clear need for explicit sustainable purchasing rules to establish a certain threshold level of sustainability in the project.

5.1.3. Construction Phase

During the construction stage, the winning contractor is obligated to achieve the carbon footprint reduction as promised in the MKI during the bidding. One innovation is the use of recycled rebars in concrete construction. This choice is driven purely by the contractor’s interest due to the MKI’s emphasis on reducing emissions within the project framework allowed by the functional specification system. In discussions with the contractor, it was confirmed that this innovation was chosen due to its maturity in the market, which assures that its application carries no risks within this project. Furthermore, according to formal procedures, the client organisation requires that any innovation achieve a TRL of 9 before it can be implemented unless the client approves it.

> **"New questions of which you haven't been thinking before for mitigating this risk, you want to make the contract as clear as possible while leaving enough space for the contractor to give him his expertise. That's always very hard. It's always a balance on which you have to find the right spot"- HRP1**

In addition, it has been noted that maintenance and asset management teams are reluctant to use sustainable alternatives. This reluctance stems from the project's lifecycle, where the project, upon completion, will be transferred to the asset team. Certain valuation methods are also used by asset tea, such as total cost of ownership (TCO). However, the project team typically focuses on the short phases of the project—from initiation to commissioning—while the asset team is responsible for the longer-term management, from handover through the use phase and up to demolition. It is essential within the organisation that the project team secures an agreement with the asset team in advance regarding the application of any innovations; otherwise, the project cannot be transferred to the asset team.

> **"It's very important because, after the project, the project team disappears, you know, we are not there anymore, and then the asset management team has to deal with the product"- HRP1**

5.2. Case B: Quay Wall Renovation Project (QWR)

5.2.1. Organisational Response to Sustainable Innovations

In this project, the organisation has already acknowledged the carbon emission targets and the concept of circularity for 2030 and 2050. This urgency is also recognised by senior positions within the organisation. The sustainability advisor also serves as a liaison between the operational and the strategic levels. Despite the existence of high-level targets, the organisation recognises the absence of concrete measurements or key performance indicators for both the organisation itself and the infrastructure project team. At present, most respondents claim that the organisation is in the process of developing tangible measurements for the reduction of carbon emissions to meet these targets. The sustainability team has noted difficulties in translating sustainability goals into tangible aspects, particularly in infrastructure projects. Furthermore, respondents identified a missing feedback loop for policymakers from the project team.

> **"There is not much re-evaluation, like a policy stating the ambition and the goals, and then operations like, OK, we need to do something with this, but there is no feedback as we did so much in circularity or something. So that's really it".- QWR5**

During interviews, respondents noted that the capability of the in-house engineering team is above average compared to other public client organisations in the Netherlands. The organisation frequently advises other municipalities or provinces on infrastructure projects. Additionally, the interviews revealed that there is a good level of trust between teams or departments within the organisation, particularly with the engineering team, which is beneficial for initiating innovative projects.

Interviews also revealed a balanced worker profile, with individuals who are ready for innovation and those who are more conservative. However, most respondents noted the absence of a systematic roadmap for innovation within the organisation, with most innovations depending on personal interest.

From the maintenance team's perspective, sustainable innovations like green concrete face significant barriers during implementation, primarily due to the presence of uncertainty and challenges in transferring knowledge to the maintenance team. To prioritise these uncertainties, the team usually relies on proven records or past innovations. Additionally, the asset team acknowledged that although there is intensive knowledge development during project execution, there is often a failure to transfer this knowledge to the asset team, or the necessary maintenance knowledge is not yet available. Moreover, there is no established protocol for knowledge transfer within the organisation.

> **“There’s so much knowledge created during the process, which at the aim of making the construction, is that transforming all that knowledge to maintenance isn’t a priority.”- QWR3**

Compared to other regions, although the organisation has executed many projects, the number of upcoming projects is not as extensive as in other provinces in the other parts of the country. This situation is seen as a good time to innovate, as there is currently available capacity within the organisation for such endeavours.

5.2.2. Overall project management phases

Geopolymer concrete is being employed to renovate the bicycle path’s quay wall sections. Actually, the global scope includes multi-parties of public client organisations involved in water infrastructure projects. Despite the involvement of multiple parties, the decision to use geopolymer concrete falls within the organisation itself for the evaluation process. However, before implementing geopolymer concrete, the client organisation must secure approval for the building permit, as it uses a new material. However, there was no significant barrier to getting that permission.

In this project, the client organisation independently manages the project without the assistance of an engineering consultancy. The preparation of bidding documents, the tendering process, and construction supervision are conducted using the organisation’s internal resources. However, the development of the geopolymer mixture for the concrete is undertaken in collaboration with a university. Post-construction monitoring is planned in partnership with an independent research company. During the interviews, respondents acknowledged the innovation’s benefits in reducing carbon emissions but noted the possibility of reworking previous inventions. However, they also mentioned that exploring geopolymer concrete provides a valuable learning opportunity for the organisation. Furthermore, respondents recognised that such innovations typically do not come from the market without client-driven initiatives. The client should be willing to give the information first to the market.

> **“On the other hand, I think it’s already been used in Australia and Russia, and I don’t know if it’s already been used in Indonesia. I think there’s more knowledge to be found in the rest of the world, and it’s good that we are trying it now in this project, but I think the Dutch saying is ’a deal of rediscovering the wheel’, and that means something like you’re discovering the wheel again, and I think that’s what we’re doing. I think we could learn a lot more by collaborating or cooperating with other countries where they’re already building it “ - QWR4**

Several factors influence the broad acceptance of this geopolymer project. Firstly, the project’s pilot status is well-recognised among stakeholders. The engineering team also implemented the geopolymer project in less critical construction areas and within a small portion of the overall project. Previous communications and successful projects by other client organisations help increase the confidence. Moreover, respondents view the high-level management within the organisation as realistic persons; they perceive the pilot project as an opportunity not only to achieve success but also to learn from potential setbacks.

> **“Be transparent. Know what the risks are. Be willing to accept these risks, but also, if there is a setback in the development during the project, it could be a setback in time and financial level, and they have to be prepared to accept that.” - QWR4**

In contractual terms, the project does not demand the same warranty level for geopolymer concrete from the contractor as it does for traditional materials. Currently, the project is engaged in preliminary tasks such as mixture development and subcontractor selection. Technically, high requirements of carbonation, freeze-thaw, and chloride corrosion pose a challenge in mixture development since the concrete will be in direct contact with water. In the mixture research, the presence of alternative materials, including bio-fly ash (0-15% of mass) and super absorbent polymer, are tested for paving the way to be more sustainable.

During the discussion with the concrete producer, there were several concerns regarding the curing time of the concrete inside the moulds since they need to use them for the next cycle within 16 hours. Another concern is the delivery of recycled aggregate, as the concrete producer usually buys the material from the nearest site. However, in this case, the concrete producer needs to purchase material for a distance due to the similar sample in the laboratory. There is also concern regarding sustainability for transportation, and the material itself creates an interesting finding during the discussion. The project team continues to explore potential opportunities and barriers as the project is still in the construction phase of preparation.

5.3. Case C: Bicycle and Pedestrian Bridge Project (BPB)

5.3.1. Organisational Response to Sustainable Innovations

In this case, the local client organisation also acknowledges the mandates to achieve the CO2 reduction and circularity targets set for 2030 and 2050. However, most respondents realised during the interview that there is no stepwise approach to achieving these targets. Consequently, there are no specific targets mandated for engineering and facility management within the organisation. The targets remain at the higher organisational levels.

> **"We don't have, for example, we don't have a stepwise approach that we say in 2024, we have, 24 percent circular and then 25%, 26%, something like that" - BPB1**

Additionally, the interviews revealed that innovations in geopolymer concrete are heavily reliant on the personal interest or internal motivation of the engineering team. On the other hand, the capability of the in-house engineering team in the client organisation is recognised also as being above average compared to other public client organisations in the Netherlands. The organisation possesses extensive expertise in various fields and disciplines, such as concrete and asphalt. This expertise is identified as one of the primary tangible drivers for implementing geopolymer concrete in the project. Furthermore, the respondents claimed that the adoption of innovation in this project is not due to the high future demand for concrete, as the organisation might construct less in the future, but rather the discovery of new materials, which is seen as a key factor.

> **"You know, in all honesty, it usually comes down to a couple of colleagues, which I happen to be one, who seems to have a more intrinsic motivation to do these things" - BPB1**

Moreover, at this level, the client organisation also recognises that there should be a willingness to accept a certain level of risk if they wish to implement a radically innovative project. The respondents acknowledge that this project involves a high risk of uncertainty that can't be transferred to the other party, especially concerning the long-term performance, which the organisation is prepared to accept. They understand that as a public client, their risk acceptance appetite is comparatively high relative to other public client organisations in the Netherlands.

> **"No, it's impossible to give the warranty because there is not enough research on the end results and the lifespan of the geopolymer concrete. So now there are no warranties. No, it's a risk for the client." - BPB2**

Furthermore, respondents emphasised that protection against this level of risk can only be ensured if the organisation adopts a dual approach to the project, which considers not only the project management perspective but also an engineering viewpoint. For example, the organisation cited past experiences with the use of Fibber Reinforced Glass (FRG) in bridge projects. According to the project management perspective, the client organisation was protected by a warranty of up to 100 years; however, in reality, two years ago the contractor went bankrupt. This incident highlights the importance of having an engineering approach to manage risks in such projects today.

> **“For example, if something happens to the bridge, the mayor and the Alderman from City Hall don’t come knocking on the contractor’s door. They come to us. What did you do? What did you buy? What kind of risks do you accept and why? And if we have to say, well, he said it was good, and I just assumed he was right and sorry. You know that’s bad. That’s not the way to go.” - BPB1**

5.3.2. Project Management Approaches

In general, the organisation managed everything from initiation and engineering design to procurement and construction supervision using internal resources. External engineering consultancy companies were not involved. However, to develop the geopolymer mixture, the client organisation established collaborations with educational institutions. During interviews, respondents indicated that although no specific procedures or protocols distinguish pilot projects from regular projects within the organisation, this geopolymer bridge was recognised by most project team stakeholders as a pilot project. This recognition facilitated a good understanding between the project and asset teams within the organisation, preventing conflicts of interest between short-term and long-term objectives from becoming a barrier in this case.

5.3.3. Design and Tendering Phase

Initially, as this innovation required a higher budget, the organisation adapted its budgeting process. Recognizing the innovative status of the project, the asset team pooled budgets from various departmental sources to fund the project. During the engineering design process, the team adopted a conservative approach, designing the bridge without significant modifications to its appearance or conventional reinforcement, and opted for lighter construction materials suitable for pedestrian and bicycle bridges, which do not bear heavy loads.

> **“We made a very conservative structural design. So, there is nothing too fancy, such as small short pads, stubby decks, simple supports, etc. But in the end, you can’t guarantee anything” - BPB1**

During the procurement or tendering process, several changes were made compared to conventional projects. There was a significant expansion in the scope and timeline that allowed the contractor to perform testing due to the absence of standardised norms and product certifications for the concrete product. This also included comprehensive load testing of the bridge post-construction by the contractor and additional time for testing the mixture at the university and the concrete producer. One notable adjustment in this project was the exemption of warranty requirements for the contractor, which was perceived by the contractor as a primary motivation for participating in the project. The contractor also anticipated that warranty exemption would be attractive in the market, facilitating easy partnership acquisition in the future. During the tendering process, three companies were shortlisted, with the selected contractor claiming the partnership with a concrete producer. The partnership with an experienced producer was seen as a key enabler by the making the confidence in the tendering.

> **“I think it’s working because our partner, the company that mixes it, said that five years before this project if they had to do some other testing themselves with geopolymer concrete” - BPB3**

Contractually, the project was tendered with fully prescriptive specifications, leaving no room for contractor modification. A specific payment method was employed for the concrete material scope, which was directly reimbursed by the client organisation and not included in the project price, reducing financial uncertainties for the contractor and enabling reasonable bids. Additionally, the geopolymer mixture recipe was confidential during the tendering process and only disclosed to the winning bidder, creating a ”Blackbox” scenario.

5.3.4. Construction Phase

In the construction phase, both the contractor and client organisation perceived that their coordination and cooperation were excellent despite facing several technical challenges. One such issue was the scalability of processes from the laboratory to full project scale; for example, aggregate material impurities that could be manually resolved in the lab became unmanageable at the project level, requiring the team to accept contaminated aggregate. The conservative approach to standards ensured the project's safety despite these impurities impacting quality. Additionally, the concrete producer made significant efforts to achieve precise results, influencing several project factors, such as transportation timing.

> **"We would that was the easiest way to calculate it, but we didn't calculate the man-hours because there was also an innovation component in the project. So we took that from our own budget" - BPB2**

The concrete producer was impressed with the mixture developed by the university. This producer also noted a shift in market demand toward geopolymer, with increasing requests from other clients. The transfer of knowledge and procedures from the university to practical application went smoothly, and the producer anticipated that most concrete producers would eventually adapt to using geopolymer despite the current lack of standard product norms and certifications. In addition, economically, the concrete producer has not yet seen a significant reduction in geopolymer prices, even with increased demand.

In the post-construction stage, the contractor emphasized the importance of bridge testing as it facilitated broader acceptance of the project among stakeholders. After completion, the client organisation mitigated long-term risks by installing sensors to monitor the bridge's behaviour. Overall, respondents viewed the project as a successful example of collaboration for a geopolymer concrete project, with the client organisation highlighting extensive knowledge development throughout the project's duration. The organisation recognised the need to improve knowledge transfer from construction to maintenance and also preserve expertise within the organisation.

> **"Only when they get confronted in some sort, That's when they start learning. This is the way we learned as well because we allowed ourselves to get confronted with actually making a bridge out of geopolymer. This is the way to learn. If just reading papers. It's different. It's not the way to learn to do it. It's like with mathematical calculations. You can read a textbook, but the only way you learn is by practising it is riding a bike, or playing an instrument, or anything" - BPB1**

Table 5.1: Enablers and Barriers in Case Studies

Aspects	Findings (Codes)	HRP	QWR	BPB
Enabler	High capability of in-house engineering team		X	X
	Personal interest as the main motivation for sustainability in construction	X	X	X
	Willingness to accept higher risk			X
	Importance of having an engineering approach alongside a contractual approach			X
	Recognition of pilot status in the organisation		X	X
	Partnership with other expert organisations		X	X
	Conservative approaches in standard and design			X
	Comprehensive testing to compensate for codes and standards			X
	Warranty exemption for concrete scope		X	X
	Detailed and prescriptive specification		X	X
	Open book contracting for certain concrete scope			X
	Good level of trust between teams or departments within the organisation		X	
	Willingness to share information with the market		X	
	Realistic view of top-level management		X	
	Awareness of sustainability in recent years	X		
	Functional specification and MKI as the primary driver of innovation in the tendering process	X		
Barrier	No stepwise approach to achieving the 2030 and 2050 targets			X
	Gap between laboratory and full-scale implementation			X
	Gap between high-level and operational policies	X	X	X
	Difficulties in translating sustainable goals into tangible targets		X	
	Lack of a proven track record of sustainable innovation		X	
	Challenges in transferring knowledge to the maintenance team	X	X	X
	Challenges with precast concrete producer		X	
	Absence of tangible sustainability targets in construction	X		
	Conflict of interest with safety and maintenance	X		
	Lack of sufficient in-house engineering team	X		
	High Technical Level Readiness (TRL) score for the project	X		
	Reluctance from asset team	X		

Table 5.2: Summary of Organisational Response to Sustainable Innovations

	HRP	QWR	BPB
Organisation type	Public client	Public client	Public client
Level	Regional	Regional	Local
Recognition of Dutch 2030 & 2050 target	Yes	Yes	Yes
Specific KPIs in sustainable construction	N/a	N/a	N/a
Engineering team capacity	Low	High	High

Table 5.3: Summary of Project Management Approaches

	HRP	QWR	BPB
Concrete type	Conventional concrete (SCM)	Geopolymer concrete	Geopolymer concrete
Concrete application	Medium-high risk	Low risk	Low risk
Overall project size	Large	Large	Small
Planning and control process	Managed by engineering firm	In-house resources	In-house resources
Stakeholder awareness of pilot status	Low	High	High
Specification model	Functional	Prescriptive and detailed	Prescriptive and detailed
Main tender Criteria	Disturbance, price, and environmental cost indicator (MKI)	Price and environmental cost indicator (MKI)	Price
Payment method	Standard	Standard	Reimbursement for concrete part
Contractor warranty	Standard	Exempted	Exempted
Recommended strategy	Mandate sustainable purchasing	Jointly embrace benefits and setbacks of innovations	The project knowledge must reside within the organisation

6 Strategy (Framework) Synthesis

This chapter aims to address the fourth sub-research question: formulating a strategy for the demand-side organisation to optimise its contribution towards the green concrete transition in the Netherlands. The strategy is developed by integrating the key findings from previous research questions, which encompass an understanding of the macro level of the green concrete transition process at a country level and an exploration of effective project management strategies within the demand-side organisation at the project level.

Understanding the macro-level transition of green concrete on a national scale is crucial. Recognising these global dynamics can better position the project within this national context and identify opportunities for collaboration, knowledge sharing, and adoption of best practices. At the micro-level, delving into project management strategies is essential for ensuring the successful implementation of green concrete initiatives. Effective project management is pivotal in navigating the complexities of transitioning to green concrete, including technical, financial, and organisational challenges. By focusing on the project level, we can pinpoint specific actions and practical strategies that can be applied to optimise the use of green concrete in individual projects, thereby contributing to the overall transition goals.

The strategy for demand side organisation is translated into three different levels, including awareness regarding the current transition status in the country, understanding the organisation's characteristics, and executing green concrete projects. This categorization represents the level from the strategic to more operational perspective and large to small scale of transition scope.

6.1. Awareness of Current Green Concrete Transition in the Netherlands

According to the main findings in Chapter 4, there are several contributions and levels of awareness among demand-side organisations in the Netherlands that influence the acceleration towards sustainable concrete by 2030 and 2050 (Ministerie van Economische Zaken, 2019). In this section, a more strategic and less practical analysis is needed as input for developing strategies. Several conditions should be recognised by purchasers to accelerate the green concrete transition in the country.

6.1.1. Stakeholders' Behavior Towards Green Concrete Transition

Understanding stakeholder behaviour in the green concrete transition in the Netherlands can help demand-side organisations prepare for the implementation of green concrete solutions in their projects. This includes selecting suitable green concrete alternatives, forming partnerships or collaborations, understanding the long-term benefits of green concrete choices, and managing risks during implementation. By understanding who the current dominant actors in the cement industry are, as well as possible new entrants and their preferences, demand-side organisations can make informed decisions about which green concrete alternatives to choose for their projects.

For example, in the Netherlands, incumbent actors are interested in researching new materials like

SCM and CCUS for further emission reductions in concrete. On the other hand, there are potential new entrants at the niche level, such as geopolymer concrete, which has not been adopted by the cement producer. Understanding this key information at the national level can provide insights for demand-side organisations regarding potential partnerships and future collaborations for green concrete alternatives in their projects.

6.1.2. Future Material Availability and Nature of Bulk Industry

Following the findings on landscape pressure in the Netherlands, slag, which is extensively used in SCM CEM III cement, will become scarce due to changes in steel production methods. Since SCM CEM III has been fundamental to the country's good record of concrete carbon footprints, the availability of this material is crucial. Purchasers need to be aware that the future development and challenge of the green concrete transition will largely revolve around finding new materials to replace slag. This material is also used as a binder component for geopolymer concrete, which has been identified as a potential new market entrant. By understanding this issue, purchasers can navigate and identify which green concrete applications will significantly impact the transition process.

Moreover, due to the bulk nature of the cement industry, any future material inventions should have the potential for mass availability. This knowledge is an important factor for demand-side organisations when selecting green concrete alternatives for their projects. For instance, when implementing new cement or concrete materials in pilot projects, organisations should consider the materials used in the mixture and their future availability if they plan to expand the application to larger infrastructure projects. This factor is especially important for organisations with a vision to use these solutions in many of their construction projects.

6.1.3. Promoting the Practice of "Cement with Purpose" Concept

According to market and user preference findings, demand-side organisations are expected to promote the new concept of using ”cement with purpose” in the future. This paradigm suggests that one or two types of cement will no longer be suitable for all applications in the construction project. Although this paradigm should be taught to purchasers, concrete producers, suppliers, and engineering companies, demand-side organisations need to become familiar with and educated about using various types of cement for specific applications. High-performance cement, which generally produces higher carbon emissions, should be used only in high-load and critical parts. Conversely, certain applications, such as pedestrian pathways or non-critical parts, could use more environmentally friendly cement that produces lower emissions and has lower technical performance. This is due to the higher proportion of SCM materials in the concrete, which reduces its strength.

The wise use of cement types and concrete by many purchaser organisations is expected to benefit the country at a national level. This behaviour can help save emission quotas for critical concrete applications. If this behaviour is widely adopted by concrete users, it can significantly accelerate the transition process. Furthermore, familiarity with and understanding of this concept can encourage the development of more types of cement in the market. Cement manufacturers will see the demand and respond by providing multiple types of cement. This practice should also be supported by other approaches, such as building less concrete, designing efficiently, and using modularity.

6.1.4. Contribution to Creating Aggregate Demand for Minimum Business Case and Standardisation

Discussions with main cement manufacturers and frontrunners of alternative cement reveal that one of the economic challenges in developing new green concrete solutions is the lack of minimum demand to achieve a viable business case. Consequently, most new alternative cements have higher market prices, inhibiting market acceptance by purchasers. This situation is exacerbated by the varying needs and definitions of green concrete among purchasers, making it hard to achieve a minimum level of uniformity. Awareness of this factor is crucial for demand-side organisations when deciding which alternatives to use in their projects and whether these contributions align with supplier expectations.

Moreover, discussions with buyer groups suggest that collaboration or coalition among purchasers is necessary to consolidate new alternatives with good TRL. This consolidation can help the market and new entrants improve the economic affordability of their products. Communication between purchasers is key in this transition process, especially for encouraging innovation with good maturity levels despite low price competitiveness.

6.1.5. Contribution to the Knowledge Development of New Materials

Findings in Section 4 highlight that the invention of new materials for SCM or geopolymer concrete is a key challenge in the country's transition process. Discovering alternative materials beyond slag and fly ash is crucial for maintaining current emission reduction performance and achieving targets for 2030 and 2050 (Ministerie van Economische Zaken, 2019). Demand-side organisations need to prioritise this issue, especially when implementing green concrete pilot projects. Self-evaluative questions should be considered, such as the project's contribution to the development of new materials. Purchasers should recognise the impact of pilot projects or participation in the invention of new materials in the green concrete transition process.

This contribution can be achieved through different development approaches, including the invention of new materials, achieving maturity of current candidate materials, or understanding material behaviour towards specific challenges in concrete parameters. Demand-side organisations are also expected to allow various pilot or demonstration projects using different materials. This environment is needed to create a conducive niche for evolution and variation, which is important at this level.

6.2. Understanding the Organisation Characteristics

After understanding the current status of green concrete and the expectations of demand-side organisations, this section aims to help organisations understand their responses to sustainable innovations like green concrete. This layer provides managerial and practical perspectives on green concrete application. By recognising organisational characteristics, more suitable execution strategies for implementing green concrete in projects can be developed.

6.2.1. Front Runner or Risk-Averse Purchaser?

Following the findings at the macro and project levels of the green concrete transition, two major characteristics of purchaser organisations are identified: front runners and risk-averse purchasers. Front-runner organisations initiate and adopt various types of green concrete innovations in the Netherlands, such as geopolymer concrete, new SCMs, and recycled aggregates. These organisations are more willing to accept part or even all of the risks related to the application of new concrete. However, statistically, the presence of these organisations is still a minority in the Netherlands. On the other hand, the vast majority of organisations are identified as risk-averse; they tend to stick with innovations that have a high level of maturity or TRL. They avoid taking on additional risks in projects. This preference is influenced by many organisational factors and project characteristics.

Understanding these characteristics can help organisations create suitable approaches for selecting and executing green concrete innovations in their projects. For example, risk-averse purchasers could be introduced to new innovations with higher maturity levels and/or could create partnerships with other organisations that have experience and track records in green concrete projects. This partnership method could increase the confidence level of risk-averse purchasers in accepting more risks in their projects. In contrast, front-runner organisations could serve as laboratories for more experimental or radical innovations, especially those with low maturity levels (TRL).

6.2.2. In-House Engineering Capability of the Organisation

Following the findings in Section 5, the size and capability of the engineering team in the purchasing organisation influence their preference and behaviour towards sustainable innovations in construction. organisations equipped with more in-house expertise are more ready to experiment with projects than those with minimal expertise. The presence of experts in an organisation can motivate the adoption of sustainable innovations in projects, as they understand the risks during implementation and provide intrinsic motivation to the project team to be more sustainable. Moreover, findings in Section 5 also show that personal interest or intrinsic motivation plays a key role in an organisation's willingness to adopt green concrete innovations, given the absence of mandatory sustainable purchasing rules in the organisation.

By understanding the level of expertise within an organisation, suitable execution strategies can be developed. For example, organisations with minimal in-house technical expertise could consult with engineering companies to gather knowledge about green concrete alternatives available in the market and prefer incremental innovations over radical approaches. In addition, the procurement strategy could involve using sustainable purchasing tools, such as the environmental cost indicator (MKI), to encourage innovation while the risk of innovation is primarily absorbed by the contractor.

6.2.3. Organisational Rules and Targets in Sustainable Construction

Following the findings in Section 5, most organisations experience a gap between high-level policies and operational practices in sustainable construction. For example, while organisations recognise the emission targets for 2030 and 2050, they often lack specific annual CO2 reduction targets for individual projects. Additionally, organisations struggle to translate CO2 reduction targets into practical construction parameters. This gap disincentivises project teams from implementing sustainable practices, leading them to prioritise traditional project goals such as time, budget, and scope.

Therefore, before implementing sustainable innovations in construction, such as green concrete, organisations should analyse and compile current operational regulations regarding sustainable construction that may include Key Performance Indicators (KPIs) or criteria for project acceptance. By understanding the extent of these regulations, both the project team can develop more suitable purchasing strategies, such as selecting appropriate contracting types that align with organisational rules.

Additionally, understanding existing regulations allows organisations to identify the real motivators and barriers during implementation. For instance, during the case study, the absence of sustainable KPIs in construction projects meant that most innovations were driven by the personal interest of team members rather than by a structured system.

6.3. Executing the Project with Specific Strategies

In this section, practical strategies are prepared to optimise the contribution of demand-side organisations when adopting green concrete alternatives in construction projects. According to the findings in Section 5, suggested strategies will be explained following the common project phases from initiation to project closure.

6.3.1. Initiation Phase

The willingness to accept higher risk by the client is crucial in this phase. In the case studies, most innovations are perceived as radical, and neither contractors nor the market are ready to assume the risks associated with sustainable concrete, such as geopolymer concrete. This condition is also supported by the traditional view of concrete as a durable and long-lasting material. This discussion should be emphasised within the client's team during project initiation. Additionally, acknowledging the pilot and demonstration status of projects is important for gaining wide acceptance from project stakeholders, such as the asset team. Emphasising the pilot status can increase awareness and acceptance of the risks associated with green concrete applications. Early involvement of the asset team is also important, as they are responsible for handling the infrastructure after project closure. Involving them as early as possible can improve acceptance rates. Since green concrete or innovative projects require more budget compared to regular concrete, extra effort is needed to pool the budget from different departments within the organisation. Budget pooling also increases the level of ownership of the project across various departments.

6.3.2. Design and Planning Phase

In this step, the selection of applications is key when applying green concrete alternatives. The design team is advised to apply geopolymer or new SCM materials to low-risk, low-load, and removable parts to measure the application risk. This approach is supported by a stepwise methodology, applying innovative concrete from low-risk, low-volume areas and gradually expanding. It is suggested that the innovative scope should be confined to certain parts of larger projects. Additionally, more conservative standards and design approaches should be applied to allow a margin of error for uncertainties in green concrete. The design team is advised to avoid setting border or edge values when applying green concrete.

6.3.3. Tendering and Contracting Phase

During the procurement phase, several adjustments should be made to secure the implementation of green concrete. Firstly, purchaser organisations should consider using either prescriptive detailed specifications or functional specifications when delivering projects to tender. Each method has specific advantages and disadvantages depending on the nature of the innovation. Detailed specifications are beneficial if the client organisation wants to steer the market toward more experimental projects with low maturity levels (TRL). On the other hand, functional specifications combined with the environmental cost indicator (MKI) can encourage contractors to use low-carbon concrete solutions that are already mature in the market.

The second strategy involves conducting pre-market consultations before delivering the project to the market. This methodology is beneficial, especially for radical innovations requiring insight into available candidates in the market. Additionally, open-book contracting practices are suggested for certain parts of the concrete to reduce uncertainty for third parties. In the case studies, contractors are advised to use a reimbursement method only for the concrete material. This method can reduce the contractor's risk of price hedging due to uncertainty. Since concrete is traditionally seen as a durable material, contractors usually avoid providing normal warranties for sustainable concrete. Exemptions from warranties should be considered for green concrete, especially for innovations with unknown performance or low TRL. This absence should be compensated by the client through additional testing or monitoring scopes in the project.

6.3.4. Construction and Closure Phase

organisations should consider adding extra scope and time for extensive and comprehensive testing for the project. This is necessary to compensate for the lack of warranties and to ensure equivalency with current codes and standards. Innovative projects, such as those involving new materials or geopolymer concrete, generally require equivalency testing before solutions can be applied. This testing is also needed to mitigate the gap between lab-scale and project-scale applications. Furthermore, in the post-construction phase, most projects employ monitoring to observe the behaviour of the concrete, especially during the early years of its lifespan. Monitoring can also be performed in cooperation with third parties.

6.4. Framework development and guidance

Based on the national expectations for contributions from demand-side organisations and the strategies suggested at the project level, a main framework has been developed following that structure. The strategies are categorised into strategic, tactical, and operational spheres, adopting a transition management framework for sustainable development (Loorbach, 2010).

In the figure 6.1. The higher-level sphere represents a more strategic approach intended for use by top-level management in the organisation or purchaser organisation. At this level, the detailed strategies from the framework are primarily used to determine the suitable green concrete solutions to be implemented in the organisation or project. This layer of the framework can also be used to evaluate the feasibility or decision to proceed with using green concrete in a project. Additionally, organisations can use this approach to develop internal roadmaps or programs for incorporating green concrete. Furthermore, this layer can be utilised by coalitions of purchasers or buyer groups in the country to develop suitable strategies for national use. In conclusion, this layer aims to raise awareness among demand-side organisations about developments in the Dutch concrete sector.

The middle layer combines strategic and operational elements. Demand-side organisations are encouraged to understand their characteristics to select suitable green concrete alternatives while preparing project management strategies for execution. This layer is recommended for program managers or their equivalents in demand-side organisations to understand.

Lastly, the lowest layer is the most technical and operational, providing specific project management strategies. These strategies are primarily derived from the findings in Section 5 and the literature review on sustainable project management. This sphere serves as guidance for the project team, including the project manager, procurement staff, and constructors, during the execution of green concrete alternatives in the construction project.

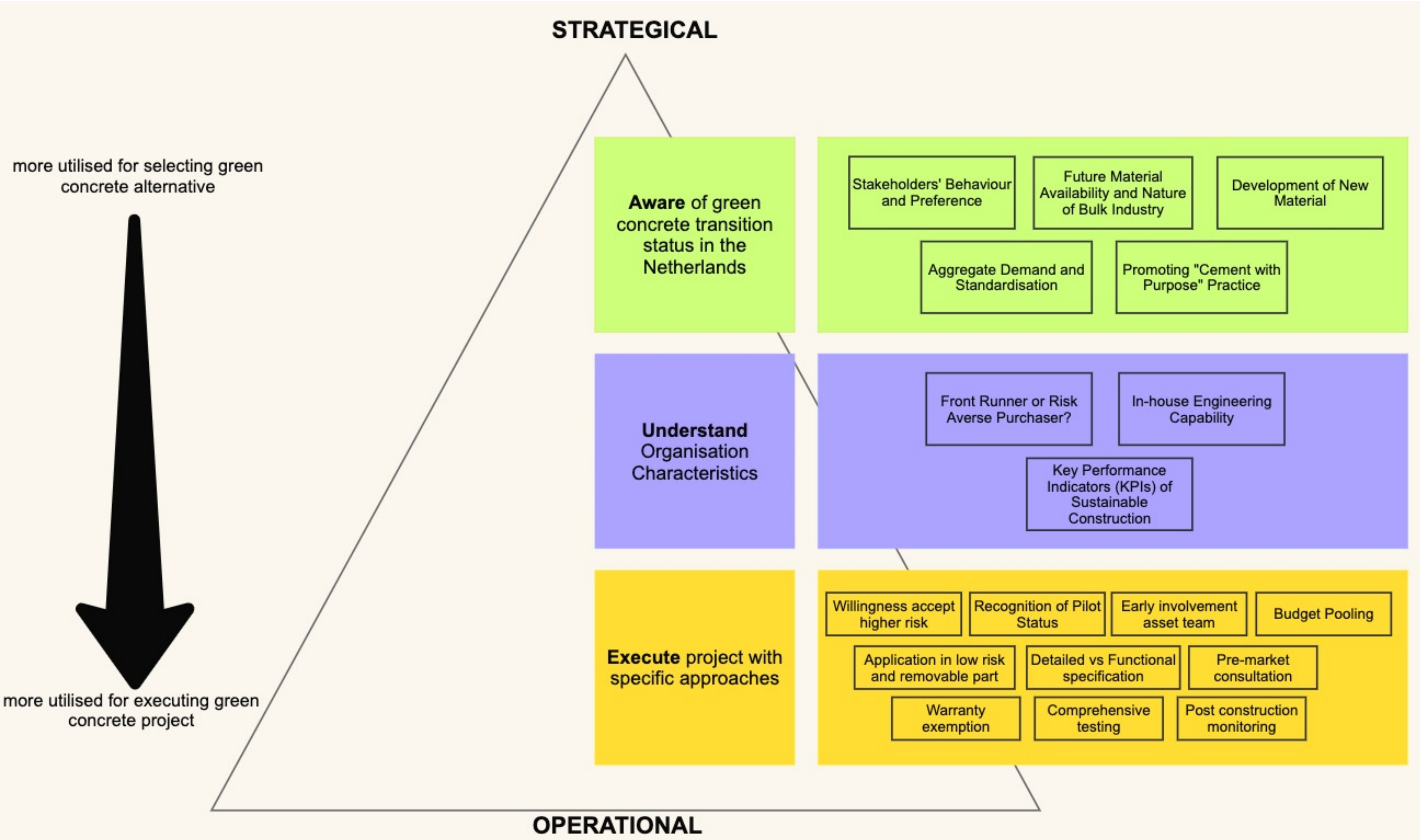

Figure 6.1: Green Concrete Adoption Strategy for Purchasers (GCAS-4P) Framework

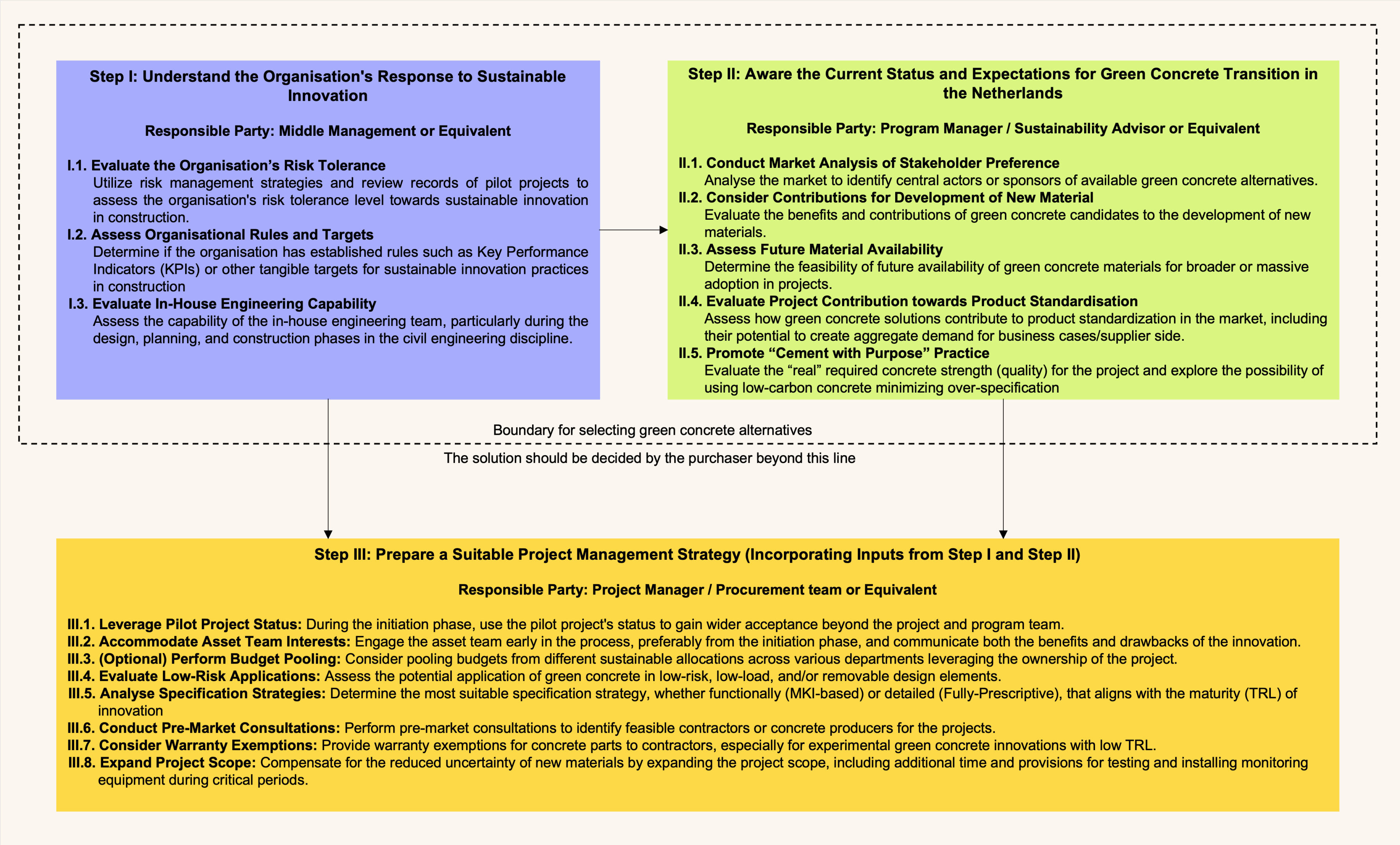

Figure 6.2: Guidance for GCAS-4P Framework Implementation

Table 6.1: Self-evaluation Questions for Green Concrete Adoption Strategy for Purchasers (GCAS-4P) Framework

Approaches	Example of Self-evaluative question	Related findings (section)
Stakeholders behaviour and preferences	Who are the incumbent and new entrants among cement producers? What are their preference regarding green concrete alternatives?	(4.2) (4.2.1)
Future material availability and the nature of bulk industry	How feasible is the future material availability for green concrete alternatives? Will these alternative materials be available in large quantities?	(4.1), (4.2.6)
Development for new material	Does the project contribute to the invention and development of new materials?	(4.2.2)
Aggregate demand and standardization	Does the project help create standardised supplier demand? Are there already near-mature solutions in the market?	(4.2.4)
Promoting "Cement with purpose" concept	What is the required strength of the concrete in the project? Does this concrete scope require high-clinker cement?	(4.2.4)
Front runner or risk averse purchaser?	What is the risk acceptance level of our project stakeholder teams? How often is our organisation involved in experimentation projects?	(5.1.1), (5.2.1), (5.3.1)
In-house engineering capability	To what extent do we depend on external engineering consultants for the project?	(5.1.2), (5.2.2), (5.3.2)
KPIs of Sustainable Construction Practice	Does the organisation have a tangible target for CO2 reduction in construction projects? How much CO2 must be reduced this year for construction?	(5.1.1), (5.2.1), (5.3.1)
Willingness to accept higher risk	How far is the failure tolerance for this project?	(5.3.1)
Recognition of pilot status	How aware are other teams of this pilot project?	(5.3.3)
Early involvement of asset team	How and when will the asset team be involved in this project?	(5.1.3)
Budget pooling	How is our project financed for the construction?	(5.3.3)
Application low risk and removable parts	Are there any low risk and low load concrete scope in the project?	(5.3.3)
Detailed vs. functional specification	Are mature solutions available in the market for the green concrete sector? Is a prescriptive and detailed specification suitable for this project?	(5.1.2), (5.2.2), (5.3.2)
Pre-market consultation	How many potential contractors are there for this project?	
Warranty exemption	Are we willing to exempt certain parts of the warranty for this project?	(5.3.3)
Comprehensive testing	How extensive is the testing to ensure the quality of this concrete?	(5.3.4)
Post construction	What monitoring is needed for this concrete during the critical period?	(5.2.1), (5.3.4)

7 Discussion

7.1. Discussion of MLP Framework Application

The MLP (Multi-Level Perspective) framework (Geels, 2002) has been utilized to explain the hierarchical relationships driving the green concrete transition in the Netherlands. This framework helps in understanding how various levels—from niche innovations like geopolymer, calcined clays, and new SCMs, to regime actors like SCM CEM cement manufacturers—interact and influence each other. The framework effectively delineates the different layers, highlighting the niche level as a space for radical, immature, and diverse innovations. This characterisation aids researchers in identifying suitable positioning of green concrete solutions and understanding the pressures and influences from higher levels, such as the EU ETS and changes in the steel industry, on these innovations.

The MLP framework also facilitates understanding potential future transformations within the Dutch concrete sector due to sustainable targets. Mechanisms such as breakout, hybridisation, and internal transformation are useful for anticipating future developments. A notable feature of the framework is its ability to explain actor interactions within the Dutch concrete sector, illustrating the dynamic between regime incumbents and niche innovators. The concept of regime actors and niche breakouts effectively represents the dominance of SCM cement in the Netherlands and the potential emergence of new entrants like geopolymer or CCUS.

However, the MLP framework has limitations in fully capturing certain aspects of the green concrete transition in the Netherlands. Firstly, it inadequately explains the top-down relationships between the regime and niche levels. In future scenarios, current cement producers might adopt niche technologies or see to the bottom, such as calcined clays and volcanic ashes for SCMs, a behavior not well-represented in the framework's predominantly bottom-up approach. The framework should incorporate two-way arrows between niche and regime levels to illustrate potential top-down sponsorship and endorsement of niche innovations.

Secondly, the framework overlooks the role of multi-actor incumbents in the transition process. Achieving concrete carbon reduction targets for 2030 and 2050 (Ministerie van Economische Zaken, 2019) requires a combination of solutions, including geopolymer, new SCM alternatives, CCUS, and reduced concrete usage. This multi-actor regime is not adequately depicted in the current framework. A modification to include the possibility of multiple incumbents at the regime level would better reflect the collaborative nature of this transition.

Thirdly, the interaction between other industries, such as the steel industry's by-products used in SCM cement, is not accurately represented. Changes in the steel industry could significantly impact SCM availability, suggesting that these industries should be considered at a similar level rather than purely higher or landscape level. Additionally, the framework lacks the capacity to explain niche innovations like CCUS, which have broader applications beyond the concrete industry and are influenced by developments in other sectors, such as oil and gas or steel.

7.2. Exploring Other Technological Transition Frameworks

Another framework that can be used to explain technological transitions is the Technological Innovation System (TIS) (Bergek et al., 2008). This framework is best suited for an in-depth analysis of specific technologies in green concrete, focusing on the interactions and functions within an innovation system. It is particularly useful for identifying and addressing barriers and enabling factors in the development and diffusion of technologies. For example, TIS can effectively explain the implementation of CCUS technology in a cement plant, a green concrete solution heavily dependent on technology. The framework provides detailed technological insights and an understanding of innovation processes in a narrower scope. However, TIS may overlook the interplay between niche innovations and established regimes, which is essential for comprehending the overall status of green concrete transitions.

Moreover, the Strategic Niche Management (SNM) framework focuses on developing and nurturing radical innovations within protected spaces (Kemp et al., 1998). It provides targeted support, facilitates learning and experimentation, and encourages stakeholder involvement (Kemp et al., 1998). For instance, SNM is well-suited for managing and accelerating the acceptance of geopolymer concrete in the broader market. However, this framework may struggle to achieve large-scale impact and transition innovations beyond the niche level. While SNM focuses on the micro-level development of geopolymer concrete, the MLP provides a macro-level understanding of how various green concrete innovations interact within the regime level or a country.

These frameworks complement the MLP by offering different perspectives for analyzing and influencing transition processes, addressing aspects that MLP may not fully cover, such as niche innovation processes and technology-centric solutions for green concrete. For example, SNM can provide a more tailored strategy for geopolymer concrete by specifically addressing its unique barriers. At the same time, TIS can offer a targeted approach for CCUS by focusing on its specific challenges. This combined approach mitigates the limitation of MLP, which tends to view transitions from a broader perspective by incorporating detailed insights from TIS and SNM frameworks.

Aspects	**SNM**	**TIS**	**MLP**
Focus	Nurturing and developing niche innovations	Detailed technological insights	Broad socio-technical systems and multi-level interactions
Key Component	Niches, actors, experiments, learning processes	Actors, networks, institutions, technological artifacts	Niche innovations, socio-technical regime, socio-technical landscape
Key Process	Nurturing innovations, learning, networking, articulation of expectations	Entrepreneurial activities, knowledge development, market formation, etc.	Breakout, regime dynamics, landscape pressures
Example of Application	Development of Geopolymer concrete	Implementation of CCUS in cement plant	Socio-technical system and interactions of green concrete innovation

Table 7.1: Comparison of SNM, TIS, and MLP Frameworks

7.3. Discussion on Sustainable Project Management

The findings reveal that sustainability goals are crucial for encouraging sustainable innovation in construction projects, aligning with the concept of sustainable project management. The literature review indicates that many scholars suggest expanding the traditional goals of project management (budget, scope, and time) (Gimenez et al., 2012) to include sustainability goals (environment, economy, and social aspects) (Pollack et al., 2018). This expansion is essential for motivating the implementation of sustainable innovations in construction projects. This paradigm is evident in the case study, where most organisations currently lack operational and tangible targets in their construction projects. Consequently, in both reference and innovative case studies, the initiation of green concrete adoption stems from the personal interest of the project team, leading to the unstructured adoption of sustainable innovations. The findings and literature review highlight the need for adopting sustainability goals in projects.

The second concept suggested by scholars in the literature is using functional specifications over-prescriptive and detailed specifications to encourage innovation by providing contractors with the freedom to innovate (Edquist & Zabala-Iturriagagoitia, 2012). However, in the case studies, this strategy is not always effective for all innovations. Functional specifications may not be effective for radical or experimental innovations, such as geopolymer concrete, as contractors are generally unwilling to assume the risks associated with new materials. Functional specifications may work better for innovations with high TRL that are already mature in the market. The empirical study suggests that fully prescriptive and detailed specifications are more effective in steering contractors toward specific innovations, particularly for demonstrating radical innovations. This is supported by the reference case, which uses functional specifications to motivate contractors during the tendering process, alongside the application of MKI to motivate the market using economic factors.

Another fundamental suggestion in the literature is shifting from stakeholder management to management for stakeholders. This concept recommends shifting the perspective from viewing stakeholders as resources to accommodating their interests (Julian et al., 2008). This approach is evident in the implementation of green concrete in both innovative cases. The involvement of stakeholders, particularly the asset team responsible for the infrastructure post-project, is crucial. Engaging the asset team early in the project can improve acceptance and ensure their interests are considered, particularly regarding concerns about the long-term performance of green concrete. In this case, the asset team is involved not only in obtaining approval or conducting gate reviews but also from the initiation of the project, including communicating the benefits and drawbacks of green concrete and developing knowledge for both construction and maintenance periods. For example, during the post-construction of the bridge in the BPB case, the project team initiated the installation of monitoring sensors to examine the behaviour of the concrete during critical periods.

However, several dimensions of the sustainable project management concept, such as agile methodology (Ciric et al., 2018) and flexible engineering, are not reflected in the empirical study. This may be due to the prescriptive and detailed specifications mandated by the client, which inhibit the use of agile methodology that relies on an iterative and flexible approach to address project dynamics. Moreover, the nature of radical innovation in the project also hinders the use of agile or flexible methodology, as the client needs to steer the contractor and concrete producer towards applying specific solutions, such as mixture cement composition or application in certain parts of the building, to mitigate risks during implementation. In this case study, the "waterfall" and deliberate planning models are more suitable governance models.

7.4. Barrier and Enabler Reflection with Literature Review

Several barriers identified in the literature review are also reflected in the empirical studies. For instance, the preference for maintaining the status quo (B-S2) is evident among the majority of concrete purchasers in the Netherlands. Although some organisations are recognised as front-runners, utilising demonstration projects for green concrete applications, most purchasers prefer conventional concrete due to uncertainties about its long-term performance. Additionally, cement producers faced similar resistance when attempting to shift the market from SCM CEM I to SCM CEM II, with many purchasers preferring SCM CEM I and turning to competitors.

The barrier of organisational resources (B-I6) is also reflected in some organisations, affecting their motivation to use green concrete. Since most organisations have not yet established structured purchasing processes for green concrete, much of the motivation stems from the personal interest of individual team members. The second empirical study revealed that the absence of expertise within organisations influences their willingness to use green concrete in projects.

However, some barriers identified in the literature review, such as the deficiency of carbon policy and guidelines (B-I1) and the shrinking domestic market (B-E4), were not reflected at the national or project levels. This is partly because the Netherlands has adopted the EU ETS system at the regional level, which pressures cement manufacturers to reduce emissions through various methods during the production process.

During project implementation, several enablers identified in the literature review were present. For instance, the Dutch tendering system uses a method that weighs price and quality in tenders (E-E2), motivating candidates to reduce emissions in their bidding proposals through the MKI system. This method provides higher scores for bidders who can demonstrate lower CO2 emissions. Additionally, leveraging the pilot project status, which increases acceptance among project stakeholders during initiation, reflects the enabler of promoting pilot projects (E-S3).

At the national level, institutional enablers such as measurable roadmap development (E-I3) and formal agreements between stakeholders (E-I2) are prominently present in the Dutch concrete sector. The establishment of the concrete agreement (Betonakkoord) in 2018 has significantly increased awareness and movement towards sustainability in the sector. Although this agreement has not yet effectively mobilised the majority of stakeholders, sustainability is no longer a taboo topic. Most forums and dialogues within the country now focus on efforts to reduce emissions.

Differences between the literature review and empirical study can be attributed to country-specific factors. These include the use of SCM-CEM III cement, regional regulations (EU ETS), a strong emphasis on sustainability (given the country's below-sea-level status), a highly educated population, and local tendering rules that differ from global norms. At the project level, deviations from the literature may be influenced by project characteristics, organisational characteristics, building codes, regulations, and environmental issues.

7.5. Practical Implications

The framework and findings provide practical guidance for demand-side organisations, offering a 'helicopter view' of the green concrete transition. This perspective helps organisations understand their influence and role in the transition. For example, when considering the application of geopolymer in a project, purchasers can recognize the position of geopolymer among other green concrete alternatives and the perceptions of other actors, including incumbents. This macro view informs project-level practices, contributing optimally to the overall transition.

Additionally, the framework and findings guide not only frontrunner organisations involved in pilot projects but also risk-averse purchasers. Strategies such as creating aggregate demand for near-mature innovations and balancing functional and detailed specifications are outlined. The framework also suggests with whom risk-averse purchasers should partner, based on the current preferences of stakeholders towards each green concrete solution.

Moreover, the framework also provides direction for the groups or coalitions of demand-side organisations. For instance, promoting the "cement with purpose" practice requires collective action to be effective. A unified approach within a coalition can significantly impact the green concrete transition process in the Netherlands, ensuring a coordinated and substantial contribution to sustainability goals.

7.6. Research Limitation

- Boundary Significance Limitation
  The first limitation of this research is its focus on a single country's boundaries. Although the research is conducted at the national level, the significance of this country in terms of the overall volume of global cement usage is considered small. This is due to the nature of the cement industry, which is a bulk industry with more than 4 billion tons of cement produced annually. This situation creates a high sensitivity to changes at the global level. Providing a broader perspective on the transition, such as examining green concrete at the EU or Benelux level, may offer more insights into the overall transition process. For example, strategies could be developed to encourage neighbouring countries, such as France and Germany, to use slag in cement. This would increase the price of slag and enhance the economic competitiveness of research into slag replacement solutions.
- Regional and Municipal Organisation

The research is limited to the regional and municipal levels of organisations. National public client organisations and the private sector are absent, which may significantly contribute to concrete volume. Additionally, higher-level organisations may have more structured policies regarding low-carbon concrete.

- Concrete Decision-Maker Bias
  This research has not fully captured the role of intermediate demand-side actors or purchasers, such as engineering consulting companies, which might play a role in the demand or purchase of green concrete. The case study initially presumed that the decision-making process for selecting green concrete adoption in projects mostly lies within the client or demand-side organisations. However, the role of engineering companies, which may hold knowledge of innovation, was not fully considered.

7.7. Recommendation for Further Research

- Supplier's perspective
  Given the limitations of this study, which focuses primarily on the demand side of the organisation, future research should explore the role of the supplier side in accelerating the transition to green concrete in the Netherlands. By examining the supplier's perspective, researchers can provide a comprehensive analysis of strategies that align the expectations of concrete buyers with those of cement and concrete producers. Future studies should also include more respondents from cement manufacturers and concrete producers. Additionally, it is essential to gather insights from stakeholders involved in CCUS technologies, as these innovations are currently favoured by the majority of cement manufacturers.
- Competition between CCUS and Front-end carbon reduction method
  At a macro level, it is crucial to investigate the current competition between green concrete innovations aimed at reducing emissions at the production stage, such as geopolymer concrete, SCM, and practices to reduce concrete usage, versus end-of-pipe solutions like CCUS. Understanding the relationship and influence between these innovations is imperative, as the pace and development of one can significantly impact the other. For example, significant advancements in the maturity and economic feasibility of CCUS could affect the development of new SCM materials and geopolymers. Unveiling these relationships can provide valuable insights for developing transition strategies at both national and organisational levels.
- Case study from Regime's endorsed project
  It is worthwhile to examine case studies of green concrete initiatives that are endorsed or sponsored by incumbent cement manufacturers. The current research primarily focuses on innovations initiated by purchasing organisations. Investigating cases where innovations are backed by established manufacturers can offer different strategies, particularly in stakeholder management and contracting. Examples of such innovations include new SCMs using calcined clays, volcanic ashes, and natural pozzolans.
- Case study from national public client level
  Furthermore, future research should explore green concrete innovation practices in organisations with a clear roadmap for sustainable concrete, such as Rijkswaterstaat and ProRail. These organisations have more structured approaches to sustainable concrete and can provide additional perspectives on organisational strategies that have a broader national impact.
- Research on role purchaser for reducing concrete usage
  it is essential to understand the role of purchasers in promoting practices that reduce concrete usage in building construction. Practices such as modularity, design for disassembly, and efforts to extend the lifespan of concrete structures were not elaborated on in this study. Exploring the purchaser's role in promoting these approaches is crucial for reducing emissions in the Dutch concrete sector.

8 Conclusion

This research aims to optimise the role of demand-side organisations such as national public clients, provincial and municipal authorities, and private sector entities that use concrete in their construction projects. To prepare effective strategies for these organisations, several sequential studies were conducted, focusing on understanding the concept of green concrete, the current status of its transition within the country, and the enablers and barriers encountered during project execution.

The 1st Sub-Question: What is green concrete, and what challenges and opportunities does it present in the built environment?

Scholars commonly define green concrete as any effort within the concrete lifecycle to reduce CO2 emissions, decrease energy reliance, reduce harmful substances, lower clinker content, and utilise recycled materials. The concrete lifecycle spans from material extraction to demolition. Key enablers identified include government incentives, the ability to combine with OPC, carbon pricing, and proven CO2 reduction. Conversely, significant barriers include higher costs, lack of regulation, negative perceptions of waste materials, and uncertainty about long-term performance.

The 2nd Sub-Question: How is the transition to green concrete in the Netherlands described by the Multi-level Perspective (MLP) Framework?

Experts generally consider the Netherlands to be advanced in sustainable concrete, largely due to the prevalent use of SCM CEM III cement with only 50% of the clinker. The SCM CEM cement producer is perceived as the incumbent at the regime level. However, potential threats from the landscape level, such as future slag scarcity due to changes in the steel industry, could challenge the transition process or even threaten the current good record. Currently, cement producers experience pressure for emission reduction mainly from the carbon pricing EU ETS, responded to by adopting gradual innovations, such as new SCMs and calcined clays, and radical innovations like CCUS. There are dynamics in the socio-technical aspects of the Dutch cement sector, including ineffective mobilisation of market coalitions or agreements, the need for purpose-driven cement, and the perception of concrete as a safe material. At the niche level, the Netherlands is seen as a favourable environment for experimenting with radical innovations in low-carbon concrete, such as geopolymer or new SCMs, due to highly educated people, limited landfills, and high awareness of sustainability. Experts agree that achieving the 2030 and 2050 targets will require a combination of all possible green concrete solutions rather than depending solely on SCM CEM III.

The 3rd Sub-Question: What enablers and barriers do demand-side organisations face when considering the adoption of green concrete at the project level?

A common challenge at the organisational level is the lack of stepwise and operational sustainability targets in construction projects, despite the recognition of broader 2030 and 2050 emission and circularity goals. Sustainable innovations like green concrete mostly rely on personal interest, leading to unstructured purchasing practices. Additionally, reluctance from other teams, such as asset management, due to uncertainties about long-term performance, poses a barrier. On the other hand, significant enablers for implementing green concrete in projects include in-house engineering capability and high-level risk acceptance within the organisation. During project execution, several shifts are identified as enablers for adopting green concrete, including recognition of the pilot status of the project, early involvement of asset teams, prescriptive and detailed specifications, warranty exemptions, extensive testing, and investment in monitoring during critical periods.

The 4th Sub-Question: What strategies can demand side organisations develop to increase the adoption of green concrete at the project level?

These strategies are formulated at three levels: strategic, managerial, and practical. The strategic level is intended for choosing suitable green concrete solutions during the initiation phase and is suggested for use by top-level management or decision-makers in the organisation. Demand-side organisations should be aware of cement and concrete stakeholder behaviour and preferences, future material availability, the bulk nature of the cement industry, creating minimum business case demand, standardisation, and promoting the "cement with purpose" concept. The managerial level combines practical and managerial perspectives, mostly for middle management or program managers, such as identifying front-runners or risk-averse characters and leveraging in-house engineering capabilities. Practical strategies for executing green concrete projects include accepting higher risks, involving the asset team early, analysing detailed versus functional specifications, conducting market consultations, and performing additional testing. This layer of strategy is prepared for the project team working on green concrete or sustainable innovation projects. The overall strategies are presented in an integrated framework and supported by examples of self-evaluative questions for guidance.

Main Question: How can demand-side organisations stimulate the adoption of green concrete at the project level?

By implementing their projects, demand-side organisations are expected to provide large field laboratories for green concrete innovations, particularly those with experimental or radical characteristics and low TRL. For near-mature innovations with higher TRLs, purchaser organisations are expected to create aggregate demand, ultimately achieving the minimum business case for suppliers to provide economies of scale for these innovations. Additionally, through their projects, demand-side organisations can accelerate the transition by promoting the "Cement with Purpose" concept, which explores the possibility of using cement for specific applications based on the actual required quality or strength of the concrete. This approach allows for the application of green concrete solutions that may initially have lower technical performance. At the knowledge development, project demonstrations by purchasers are expected to contribute to the development of new materials for replacing slag in the future.

During the practical phase, purchaser organisations are encouraged to accept higher risk levels towards sustainable innovations, such as considering warranty adjustments. Furthermore, demand-side organisations can optimally contribute to the transition by upgrading their in-house engineering capacity to retain and enhance knowledge within the organisation. It is also suggested that organisations assess potential applications of green concrete, especially for low-risk and removable design elements. Lastly, demand-side organisations are expected to leverage the pilot project status to gain wider acceptance during the initiation of innovative projects.

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A

Interview Questions for National Level

Table A.1: Interview Questions and Topics

Topics	Questions
Background	• Could you explain your background and experience with concrete?
Overall Transition Status	• What do you think about current implementation of sustainable concrete in the Netherlands? • Example Follow up questions: – Could you share the story of establishment of Bettonakkord? – What are the current enablers and challenges of green concrete transition in the country? – Are you optimistic that the target will be achieved in 2030 and/2050?
Niche Development	• What are your opinions regarding current green concrete solutions, such as geopolymer, SCM, and carbon capture? • Example Follow up questions: – What is your prediction for the dominant innovation in the future or near year of target?
Breakout Process/Windows of Opportunity	• What do you think the strategy of the scarcity of fly ash in the Netherlands for securing the CO2 emission? • What do you think the strategy to integrate fragmented innovation in the client?
Socio-technical Interaction	• How are the stakeholder preferences and behavior towards sustainable concrete? • Do you see behavior to delay transition from current concrete industry towards green concrete? • What is the strategy to deal with current code and standard? • How can buyer organizations promote green concrete to the market?
Transition Pathways	• How are the possible approaches for achieving the target in 2030 and 2050 in the Netherlands? • Example Follow up questions: – What are your suggestions to accelerate the transition process? – What is your opinion regarding carbon capture?

B

Interview Questions for Project Level

Table B.1: Interview Questions and Topics

Topics	Questions
Background	• Could you explain your experience with projects?
Project Scope	• Could you tell me about a project where you used green concrete? • Example Follow-up questions:: – Why was green concrete applied in that part of the project?
Enabler(s)	• What led to the decision to use green concrete in your project? • Example Follow-up questions: – Does your organization have tangible targets or KPIs for sustainable construction projects?
Adaptation in Project Management	• Did you have to change any part of the project initiation, design, contracting, or execution for green concrete? If so, why? • Example Follow-up questions: – What changes were needed during the tendering and contracting phases of the project? – How did you evaluate the bidding documents for this project? – What was the design approach for this project?
Barrier(s)	• What problems did you face when using green concrete in the initiation, design, contracting, or execution phases, and how did you solve them? • Example Follow-up questions: – How did you manage the uncertainty of the long-term performance of the green concrete scope?
Stakeholder Behavior	• How did stakeholders react to the use of green concrete in the project? • Example Follow-up questions: – How did you manage other stakeholders, such as the asset team, to accept this project?
Suggested Strategy	• What would be your advice for managing project initiation, design, contracting, and execution with green concrete in the future?

C
Informed Consent

Opening Statement (Interview)

You are being invited to participate in a research study titled Stimulating the Adoption of the Green Concrete in the project . This study is being done by Muhammad Artono from the TU Delft. The purpose of this research study is to provide understanding about the implementation of green concrete in the project level, and will take you approximately 45 minutes to complete. The data will be used for the master thesis of Muhammad Artono. We will be asking you to provide information related to your understanding or opinion related to the viability of the application of green concrete in the project, including the barriers and opportunities for the transition.

As with any online activity the risk of a breach is always possible. To the best of our ability your answers in this study will remain confidential. We will minimize any risks by keeping your answers and personal information strictly confidential. The interview results published on the thesis will be coded and completely anonymous. Personal information, such as name, contact information, and occupation, will only be collected for thesis related purposes (e.g., informing the study's supervisor). With your permission, the interview will be recorded and if via online meeting, the text will be automatically transcribed using Microsoft Teams. I will manually adjust the automatic transcription to match with the original interview. The original transcripts and recordings will only be available to the thesis supervisors, will not be published anywhere, and will be removed approximately two years after the completion of the study, at the latest. Your participation in this study is entirely voluntary and you can withdraw at any time. You are free to omit any questions.

Below you can find the informed consent form of the research. Please tick the boxes to indicate your consent. The contact details of the researchers are as follows.

Corresponding Researcher
Muhammad Artono
muhammadartono@student.tudelft.nl

Responsible Researcher
Yirang Lim
Y.lim@tudelft.nl

Table C.1: Participant Consent Form

PLEASE TICK THE APPROPRIATE BOXES	Yes	No
A: GENERAL AGREEMENT – RESEARCH GOALS, PARTICIPANT TASKS AND VOLUNTARY PARTICIPATION		
1. I have read and understood the study information above or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	☐	☐
2. I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	☐	☐
3. I understand that taking part in the study involves:	☐	☐
• The interview will be semi-structured with open-ended questions related to the viability of green maritime methanol in the shipping industry. • A recorded interview that will be conducted via Microsoft Teams or Face-to-Face. • If via Microsoft Teams, the recording will be transcribed as a text directly from Microsoft Teams and the researcher will edit the text by listening to the interview recording and adjusting the written transcription to the original spoken text. • The interview recording will be stored on the personal storage of Muhammad Artono on the TU Delft OneDrive and will be destroyed the maximum of two years after the study has been completed.		
4. I understand that I will not be financially compensated for my participation.	☐	☐
5. I understand that the study will end by September 2024		

B: POTENTIAL RISKS OF PARTICIPATING (INCLUDING DATA PROTECTION)		
6. I understand that taking part in the study involves the following risks:	☐	☐
• The risk of leaked business/organisation strategies. • The risk of leaked information. • The risk of reputation damage from leaked information. • I understand that these risks will be mitigated by storing the important data, such as personal information and original interviews securely, will not be made available publicly and only available to the thesis supervisors, and will be removed after the research is finished. The interview results that will be published on the thesis only in the form of aggregated data (e.g., coded interviews, codebook, and combination of analysis of all the interviews). Furthermore, I can choose how to respond to each question that may be detrimental to me or my organisation. I may choose not to respond to any of them and I have an option to end the interview at any time.		
7. I understand that taking part in the study also involves collecting specific personally identifiable information (PII) (name, occupation, contact information) and associated personally identifiable research data (PIRD), with the potential risk of my identity being revealed, the risk of re-identification and the subsequent risk of affecting my public or professional reputation.	☐	☐
8. I understand that some of this PIRD is considered as sensitive data within GDPR legislation, specifically job position and political, economic, social, technological, or environmental view.	☐	☐
9. I understand that the following steps will be taken to minimise the threat of a data breach, and protect my identity in the event of such a breach. The interview will be conducted anonymously. Personal information of the interviewees will not be published to anyone who is not involved in the research. After the research is completed, the personal data will be deleted.	☐	☐
10. I understand that personal information collected about me that can identify me, such as my name and contact information, will not be shared beyond the study team.	☐	☐
11. I understand that the (identifiable) personal data I provide will be destroyed after the research has ended, which will be conducted the maximum of two years after the graduation of the researcher.	☐	☐

C: RESEARCH PUBLICATION, DISSEMINATION AND APPLICATION		
12. I understand that after the research study the de-identified information I provide will be used for the following purposes. The anonymise interview results will be published along with the master thesis on the TU Delft Repository, including the anonymised coding of the interviews.	☐	☐
13. I agree that my responses, views or other input can be quoted anonymously in research outputs.	☐	☐
D: (LONGTERM) DATA STORAGE, ACCESS AND REUSE		
14. I give permission for the de-identified interview results that I provide to be archived in the TU Delft repository (https://repository.tudelft.nl/) in the form of anonymous coded interviews so it can be used for future research and learning. The original transcribed interviews will not be made available to the public or be stored on the TU Delft repository.	☐	☐
15. I understand that access to the repository where the master thesis is stored is openly available on the internet.	☐	☐
16. I understand that the collected data may be reused for future scientific publication and educational activities on the topic of green concrete transition in the Netherlands.	☐	☐

Signatures

Name of participant	Signature	Date

I, as researcher, have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

Researcher name [printed]	Signature	Date

Study contact details for further information:
Muhammad Artono
`muhammadartono@student.tudelft.nl`