Stimulating Innovations in the Infrastructure Programmes

Suppliers' perspective in the development and implementation of innovations in multi-projects

Master of Science Thesis

Savitri Dinar Wulandari

Delft University of Technology

Stimulating Innovations in the Infrastructure Programmes

Suppliers' perspective in the development and implementation of innovations in multi-projects

by

Savitri Dinar Wulandari

to obtain the degree of Master of Science
at the Delft University of Technology
to be defended publicly on 28 September 2023 at 12:00

Author

Name:	Savitri Dinar Wulandari
Student number:	5626633
Master:	Construction Management and Engineering
Institution:	Delft University of Technology
Faculty:	Civil Engineering and Geosciences

Supervisory board TU Delft

Chair of the committee:	Dr. Ir. Ad Straub Faculty of Architecture and the Build Environment
First Supervisor:	Dr. Ir. Maedeh Molaei Faculty of Architecture and the Build Environment
Second Supervisor:	Dr. Erik Jan Houwing Faculty of Civil Engineering and Geoscience

Company supervisor

Supervisor:	Ing. Petra Peters Royal HaskoningDHV

TU Delft

Preface

Progress is impossible without change - George Bernard Shaw

The final step into my journey towards the Master of Science degree in Construction Management and Engineering at the Delft University of Technology is marked with this graduation thesis with the title ”Stimulating Innovations in the infrastructure programmes: Suppliers’ Perspective in the Development and Implementation of innovations in multi-projects”. After years of working, I took the exciting leap back into education. This dream of mine, which has been with me since my graduation as a Civil Engineer from Gadjah Mada University in Indonesia, has never left my heart. Pursuing this dream is not just about my own personal growth but it is also about my deep commitment to making a positive impact on the ever-changing world. I believe real progress comes from embracing change. Over the last six months, my adventure into academic research has not been smooth. I’ve faced all sorts of challenges that required unwavering determination to conquer. But in those tough moments, I always keep in mind the significance of progress. It is just like my guiding star, helping me navigate through this research journey.

In this fruitful learning journey, I am fortunate to find myself encircled by a multitude of individuals who exude inspiration, and I wish to extend my heartfelt appreciation to each of them. First is my graduation committee for their patient guidance and assistance throughout the research process. I can not be more thankful to Dr. Ir. Maedeh Molaei for her valuable feedback, time, and patience in guiding me until the end of this process. Her advice on research techniques and her constructive feedback on my report have helped me to produce this research thesis report. Thank you to Dr. Ir. Ad Straub as my graduation chair whose positive attitude and critical academic insights about the research topic influence my progress. Thank you Dr. Erik-Jan Houwing who always gives me valuable feedback and keeps me thinking to improve my research. Thank you to my thesis supervisor from Royal HaskoningDHV, Petra Peters for your support, guidance, and time during my research in the company. I would like to also express my gratitude to Royal HaskoningDHV for providing me the opportunity to conduct research in the company. In this research, I have spoken and interviewed a number of inspiring people ranging from directors to project leaders. I would like to thank them for their time and their valuable insight into the topic.

Lastly, my gratitude extends to my circle of family and friends whose unwavering backing has been instrumental throughout my research. A special acknowledgment goes to my husband, Jarno de Wolff, whose unshakeable faith in me has been a constant source of strength. His consistent support and role as a sparring partner in discussions have been invaluable. To my friends, your encouragement and reminders of the ultimate goal of this research and education have kept me on track. You all collectively form my pillar of support, and thus, you too deserve recognition within the pages of this thesis.

Savitri Dinar Wulandari
Dronten, September 2023

Executive Summary

With the increasing size, activity, and complexity of infrastructure projects, the programmatic approach is increasingly chosen by the government in the Netherlands to organize multiple projects. The use of innovations arises in multi-projects within those programmes such as to be efficient and effective to achieve the goals of the programme. Despite the clear benefits of innovations, the process of the development and implementation of innovations in infrastructure programme is not a smooth path. As a result, the use of innovations is not optimized to meet the programmes' goals. Along with the rare practical use of programme by government bodies, the understanding of the context of programme and innovations in multi-projects are still limited therefore the implementation of innovations in programme still proceeds with a project-based approach. Approaching innovation with a project-based approach is problematic because innovations require time and flexibility instead of strict requirements and short time-bound. In addition, the progressive learning curve that is essentially useful in the development of innovations is not optimally utilized due to the discontinuity nature of projects. Furthermore, this project-based approach creates a continuous dilemma for the suppliers due to the lack of incentives and high risk to innovation, while their contributions to the development of innovation are essential. The gap between the understanding and implementation of innovations in infrastructure programme need to be bridged in order to facilitate the development and implementation that ultimately contribute to the achievement programme's objectives. This research therefore aims to address the problem of ineffective utilization of innovations in multi-project settings as part of infrastructure programmes.

This research addresses a significant gap in the literature by exploring the role of innovation in infrastructure programmes from the perspective of suppliers, a perspective often overlooked in existing research. Suppliers in this research context are market parties which include engineering companies and contractors. These parties can act individually or form a partnership when they work on assignments from government bodies as public clients. It aims to better understand the factors and mechanisms that drive innovation in these programs. To achieve this research goal, a main research question is formulated as follows:

How can innovations be facilitated in a multi-project setting, in order to contribute to the achievement of programmes goals?

This research is divided into four phases: I. Theoretical (Chapter 1 and Chapter 2), II. Empirical (Chapter 3 and Chapter 4), III. Framework (Chapter 4), and IV. Finalizing (Chapter 6 and Chapter 7).

In the first phase, a literature review was conducted to build a sufficient theoretical foundation for the research based on three streams of literature: programme, innovations, and innovation process. The literature review provides a theoretical background about the infrastructure programme, its goals, its characteristics, the role of innovations, and the innovation process in the infrastructure. An infrastructure programme is a unique endeavor where a collection of interrelated projects is managed in an integrated manner to achieve optimum benefits for stakeholders and organizations. The programme's overarching goals can not be achieved if the projects are managed separately. The innovation process in infrastructure is influenced by innovation elements: drivers, inputs, preconditions, barriers and enablers, outputs, and outcomes. Innovations in programmes are born as a result of programmes drivers to reach desired benefits and are stated based on the inputs. However, preconditions must be present for the innovation process to begin. In the development and implementation of innovations in multi-projects, indicated by the increasing level of Technology Readiness Level (TRL), barriers are found and enablers shall help to overcome the barriers before the output of the innovation process is utilized on a larger scale in multi-projects to achieve the desired benefit. 27 barriers and 21 enablers to innovations were found in project-based literature and they are categorized into groups: Contract and regulation, financial, collaboration and cultural, technical, knowledge sharing, client-related, and market-related.

The outcome of this first phase is a theoretical framework for the innovation process in the infrastructure programme as seen in Figure 2.6.

In the empirical phase, multiple case studies were selected based on the criteria determined from the earlier phase, allowing further analysis in the research company, Royal HaskoningHDV. The case studies are (1) Bridges and Quay Wall Renovation Programme (BQWP) where the innovation for quay wall renovation is developed under the Innovation Partnership Quay Wall (IPQ), (2) Amsterdam Road Tunnel Programme (RTR) where Digital Twin is developed in large scale to be used in multi-project renovation, (3) Eight Steel Bridges renovation (SBR) where the High-Performance Concrete (HPC) innovation was utilized in multiple bridges. The objective of this second phase is to gain an understanding of the innovation process in practice and identify the barriers and enablers to innovations seen in the multi-project as part of the infrastructure programme. By using the theoretical foundation from Phase I, the innovation process including the innovation elements is analyzed in these cases through document reviews and semi-structured interviews as the main data collection method. This method of interview allows the researcher to ask follow-up questions after the prepared open-ended questions are answered by the interviewees. The interview questions were prepared based on the topics determined from the literature review and were asked of the 11 interviewees who were selected based on their involvement in innovations in the case studies. The results of the interviews were further analyzed using qualitative analysis software, allowing the transcribed interviews to be coded/re-coded, grouped into themes, and formed patterns to be identified, interpreted, and presented as research findings. For a confidential purpose, the interview results are presented anonymously in this research.

Research findings
The main output of this empirical phase is the seven barriers and five enablers to innovations encountered by suppliers during the development and implementation of innovations that are unique for multi-projects in the infrastructure programmes. The research revealed a previously overlooked aspect in the literature: the presence of time-related challenges in innovation. These challenges stem from the prolonged innovation process and program duration. Additionally, the primary challenge of innovations in multi-projects is a technical challenge, tied to the iterative innovation process and uncertainty management, regardless of whether the innovations are radical, substantial, or incremental. These challenges are subjects of debate, as technicality and time are inherent to innovation. Technical challenges are integral and cannot be completely eliminated, while time is necessary for managing uncertainty and risks. Achieving a balance where time facilitates rather than hinders innovation is crucial. This research confirms the barriers and enablers to innovations that are known from the project literature. A contract form suitable for innovations is identified as a major enabler of innovations by suppliers. A contract such as a framework contract, early contractor involvement, or alliance contract facilitates the risk-sharing mechanism and promotes long-term collaboration. Lacking risk sharing, promoting long-term collaboration, and the presence of competition makes contracts become barriers to innovation. This further restricts the knowledge exchange with external parties while inter-organization collaboration is highly needed in innovation. In addition, two barriers related to clients were found: clients' organization size/structure and clients' organization demands which imposed strict requirements that do not provide flexibility in the development and implementation of innovations.

In addition, drivers, inputs, preconditions, outputs, and outcomes of innovations in multi-projects were identified in the case study, as seen in Table 4.20. This research revealed preconditions to innovations, unique to multi-project: (1) the presence of leadership, visions, and commitment of organizations to innovations, (2) the financial capabilities of organizations, both clients and suppliers, and (3) suitable contract form. For multi-project, on top of a guarantee of budget, knowledge, and human resources inputs, suppliers indicate that it is important to have certainty about the volume of works/number of projects to be grouped. The detailed comparison between the cases can be found in Section 4.4.

Based on research findings and the theoretical framework about innovation in infrastructure in solutions framework was built, aimed to facilitate the implementation of innovations in multi-projects. The framework is based on five practical plans and innovation boundaries, which serve as the solution to the barriers to innovation in multi-projects. Innov-Infra framework, as a product of this research, consists of sets of action plans for suppliers and public clients, which when completed, potentially mitigate

multiple barriers to innovations. Innov-Infra consists of two essential parts: the first part serves as the foundation for innovations and is established through the awareness of innovation elements that act as innovations' boundary, the second part revolves around facilitating innovations which consists of three practical plans focus on collaborations, projects/programme procurement, and development of business cases. To assess the practicality of the framework, expert sessions were conducted with the company's senior managers and public clients, and based on their inputs, the Innov-infra framework was further adjusted to help suppliers and public clients facilitate the development and implementation of innovation in multi-projects. The final Innov-Infra framework in programme can be seen in Table 5.2 and the user guidelines can be found in Table 2. It is recommended that suppliers and public clients organizations use the Innov-Infra framework at the project/programme initiations (part I) and project/programme implementation (Part II). The process of using Innov-infra should be led by an appointed person in the organization who is (going to be) involved in multi-project innovations such as a Technical manager or Project manager. Innov-Infra framework aimed to provide generic guidelines for multi-projects that can be used by both suppliers and public client organizations by providing attention points in relation to innovations in multi-projects. Due to its simplicity, it is therefore easily adjustable depending on the needs of the organization. It is also recommended that organizations continuously be aware of the innovation boundaries and identify elements that are not yet reflected in the Innov-Infra framework.

Discussions
Aside from the practical contribution that Innov-infra offers, this research contributes to scientific knowledge by conforming various theories from the literature. This research focuses on the impact of innovations in infrastructure programmes and the factors influencing innovation development and implementation in multi-project contexts. It reviews existing literature on innovation processes in the infrastructure sector, programmes in infrastructure, and procurement for innovations. While past research has mainly explored project-level innovations or programme governance, this study addresses the gap by qualitatively investigating factors contributing to innovation in programmes by analyzing multiple case studies to identify barriers and enablers from suppliers' perspectives. In addition, this study contributes to the literature by detailing the innovation process within infrastructure programmes.

This research however has limitations that are important to acknowledge. This research employs a qualitative method which relies on the subjective interpretation of the researcher for data analysis and interpretation. Another limitation is, that this research was conducted in an engineering company that generally operates based on projects and has a limited view of programme in comparison with public clients. Therefore the interviews conducted with the key personnel were influenced by a project-based perspective. The availability of the case study was also a challenge in this research because this research is conducted in one company where the case within the scope of this research is limited. In addition, this research did not look into detail the procurement for innovations, which is crucial in stimulating innovation in programme. Furthermore, the practicality of the Innov-infra framework still has to be further tested in practice since its validation was limited to four experts.

Conclusion and Recommendations
In conclusion, this research has presented the innovation process in the infrastructure programmes and highlighted the important factors, so-called, innovation elements, that influence innovations in multi-projects. It includes the barriers and enablers of innovations found in practice based on suppliers' perspectives. It is essential for both suppliers and public clients to maintain focus on the innovation elements throughout the projects/programme life cycle. The Innov-Infra framework offers a focus on these important elements and provides mitigation actions to the challenges during the development and implementation of innovations in programme.

This research provides several recommendations for suppliers, including engineering companies and contractors. The importance of clear ambitions of suppliers for innovations is highlighted, as they bring about numerous advantages such as enhanced project effectiveness and efficiency. While obstacles persist in the innovation process, it remains crucial for suppliers in the infrastructure sector to actively foster innovations, align resources, motivate employees, and position the company for growth and competitiveness. Cultivating an innovation culture within organizations is emphasized, recognizing the need for a distinct mindset and iterative learning processes. Actively sharing knowledge about

innovations is deemed essential, especially within multi-project contexts, to facilitate collaboration and advance the industry collectively. The utilization of the Innov-Infa framework is recommended as a foundation for innovation development and implementation in multi-projects, particularly in advising public clients and executing projects in the infrastructure sector. Additionally, the notion of bundling the supply of innovations to public clients through collaborative efforts is proposed as a promising strategy to overcome investment barriers and ultimately achieve programmes goals.

This research highlights the pivotal role of public clients in propelling innovations in multi-projects, with public clients' substantial influence in achieving infrastructure programmes' goals through the utilization of innovations. For public clients, it is emphasized that the organization's visions and ambitions must be translated into comprehensive commitment throughout organizational tiers to ensure resilience against political fluctuations that might otherwise compromise the innovation process. Educating the organization about the multifaceted innovation process is crucial for public clients, particularly when adopting a programmatic approach, necessitating intra-organizational cooperation to effectively facilitate innovation realization aligned with government objectives. Collaborating closely with suppliers and stakeholders during the programme's early stages is shown to expedite innovation implementation, as discussions and solutions can be promptly addressed. Encouraging long-term relational collaboration supports sustainable innovation efforts, and bundling the demand for innovations emerges as a strategic approach for enhancing cost-effectiveness while elevating infrastructure quality through shared investment across public organizations.

For future research, there are several potential combinations of research. It is recommended to enlarge the scope of the research by involving public clients and/or combinations and investigating innovations in other types of programme and sectors. In addition, a number of barriers and enablers to innovations in projects were found in the literature, and in combination with the result of this research, the list becomes longer, therefore, a quantitative research approach can be employed for future research to generate stronger outcomes. Based on this research, a contract form acts as a barrier and enabler to innovations. This raises an opportunity to investigate deeper into procurement for innovations where contract plays a crucial role in the development of innovation in multi-projects. This can be done for example by looking into more detail about the framework contract and how the bundling of projects can be organized in contract.

Table 1: Final Innov-infra Framework in programme

Innov-Infra Framework			
Part I - Boundary conditions for innovations in programme – To be applied during Projects/programme initiation			
Clarify the following innovation boundaries for (multi) projects: **1. Drivers to innovations:** - Reach desired outputs achieved with innovation (e.g deliver new or renovated infrastructure assets) - Reach desired outcomes (e.g efficiency, effectiveness, quality, learning from projects) **2. Preconditions to innovations:** - Leadership, visions, and commitment - Financial capabilities of organizations - Suitable collaboration form **3. Inputs to innovations:** - Resources (capital investments, knowledge, human resources) - Volume of works or number of projects to form a group of projects **4. Output of innovations:** Proven concept of product/process innovation in project(s) **5. Outcome of innovations:** Desired benefits (e.g efficiency, effectiveness, quality, learning from projects) **6. Aware of enablers and barriers to innovations:** - Enablers: A suitable contract forms, Knowledge exchange with external and internal parties, positive collaboration efforts, influence of networks - Barriers: Contract form, innovation cost, (client's) organization structure/size, knowledge exchange with external parties, time barriers, clients' organization demands, technical challenge	**1. Create awareness about innovation process**	**Action plan 1 for suppliers and public clients** 1.1 Sharing lesson learned of innovation development within internal organization and in external professional knowledge sharing network 1.2 Conduct frequent discussion with internal organization and external organization about innovations process 1.3 Actively participate in community networks for discussion forum, presentations, dialogues	**Responsible person** 1.1 CommM, TM, PM, SS 1.2 IM, MT 1.3 IM, MT, TM, PM
	2. Developing basic knowledge of the latest technology trends	**Action plan 2 for suppliers and public clients** 2.1 Collaborate with research and knowledge institutions (universities and research institutions) 2.2 Organising regular knowledge sharing presentation/sessions and training sessions 2.3 Assigning a knowledge champion for special interest group of technology 2.4 Following the latest development of technology in the market (local and worldwide) 2.5 Developing a knowledge database to share lesson learned on innovations in projects	**Responsible person** 2.1 SS, TM, MT 2.2 SS, TM, MT 2.3 IM, MT 2.4 IM, MT, BG, SS 2.5 IM, MT

Part II – Facilitate the development and implementation of innovations – To be applied during Project/programme implementation				
3. Focusing on collaboration efforts in projects/programme	**Action plan 3 for suppliers** 3.1 Actively networking with other suppliers/organisations to identify suitable partners from the community networks 3.2 Maintaining project teams especially for long-term projects/programme duration 3.3 Maintaining relationship with projects/programme team (e.g celebrating milestone together, using collaboration tools, promoting open communication, nurturing trust, team effort appreciation) 3.4 Assigning a dedicated Account Manager/team for a client 3.5 Actively engaging with client(s) in the innovation development and implementation	**Responsible person** 3.1 TM, SS, PM, CM, MT 3.2 MT 3.3 MT, AM, PM 3.4 MT 3.5 AM, PM, TM	**Action plan 3 for public clients** 3.1 Maintaining project teams especially for long-term projects/programme 3.2 Maintaining relationship with internal projects/programme team and with suppliers' team (e.g, using collaboration tools, promoting open communication, nurturing trust, team effort appreciation, using collaboration coach) 3.3 Monitoring collaboration process internal and external organization during the projects/programme (e.g collaboration monitor, team assessment)	**Responsible person** 3.1 ProgM, PM 3.2 ProgM, CM, PM 3.3 ProgM, PM
4. Programme/projects procurement should consider the following: • Procurement for innovations • Project delivery model support long-term collaboration • Utilizing functional requirement • Continuity of use of innovations • Award criteria supporting innovations	**Action plan 4 for suppliers** 4.1 Negotiating term and conditions on the contract to avoid disruption on innovation process (consider innovation boundary in Part I) 4.2 Advising the client about the choice of collaboration form to promote innovation during market consultations/ discussion points with clients 4.3 Ensuring the continuity of innovation outside the programme	**Responsible person** 4.1 CM 4.2 MT, IM, CM 4.3 MT, IM	**Action plan 4 for public clients** 4.1 Selecting tendering procedure that promoting innovative solutions (competitive dialogue, innovation partnerships, SBIR) 4.2 Using Project delivery model promoting long-term collaboration between clients-suppliers and eliminating competition (framework agreement, alliance, two stages approached with early contractor involvement) 4.3 Incorporating functional requirements 4.4 Engaging internal & external stakeholders to formulate realistic requirements for tender 4.5 Using award criteria based on quality and/or best value 4.6 Engaging suppliers at earliest possible in the programme/projects 4.7 Making considerations the continuity of innovations outside the programme	**Responsible person** 4.1 CM, ProgM 4.2 CM, ProgM 4.3 CM, TM, PM, AsM 4.4 ProgM, PM, TM 4.5 CM, ProgM 4.6 CM, ProgM 4.7 ProgM, CM, BG, AsM
Practical plan 5. Development of business case should consider the following: • Lifecycle analysis • Criteria to bundle/group projects • Reasonable time frame for innovations development	**Action plan 5 for suppliers** 5.1 Advising bundling supply for various public clients 5.2 Suggesting criteria for grouping projects (e.g locations, types of assets, complexity of assets/works) during market consultations/ discussion sessions with clients/ project closure 5.3 Proposing a reasonable time frame for innovation development 5.4 Ensuring inputs of innovations are guaranteed from internal organization	**Responsible person** 5.1 MT, IM, AM 5.2 MT, IM, AM, SS, PM 5.3 PM, TM 5.4 MT, PM	**Action plan 5 for public clients** 5.1 Using life cycle perspective to justify the cost of innovation 5.2 Planning a sufficient time to develop innovation (consider trial and error process/learning process) 5. 3 Identifying capability and capacity of the suppliers and/or cross sectoral actors by using formal mechanism (market consultation) or informal mechanism 5.4 Ensuring inputs of innovations are guaranteed from organization 5.5 Creating sufficient demands to innovations by identifying assets to be bundled and develop bundling criteria	**Responsible person** 5.1 ProgM, CM, AsM 5.2 CM, PM, TM 5.3 CM, PM 5.4 ProgM, PM 5.5 ProgM, CM, PM, AsM

Table 2: Innov-Infra user guidelines

Innov-Infra User Guidelines

General Information

- Innov-Infra framework is a two parts framework, highly recommended to be used by organizations when innovation(s) is considered to be used and/or going to be developed/implemented in multi-project/programme.
- Part I should be used during programme/project initiation and Part II during programme/project implementation
- The responsible person listed in this framework are using the abbreviation as per following functions but not limited to:
  - Technical Manager (TM)
  - Project Manager (PM)
  - Contract Manager (CM)
  - Account Manager (AM)
  - Innovations Manager (IM)
  - Management team (MT)
  - Communication Manager (CommM)
  - Buyer groups (BG)
  - Specialists (SS)
  - Programme Manager (ProgM)
  - Asset Manager (AsM)
- The above functions are the typical function in the organization who potentially use the Innov-Infra in multi-projects in suppliers and/or public clients' organization
- It is highly recommended to assign one person in the organization (can be from the list of function above) to lead the process of using Innov-Infra
- It is possible to assign the action plans to multiple responsible persons in the organization
- Suppliers in this context are market parties, consist of engineering and consultancy companies, contractors, and companies supply chain
- It is suggested for organization to add steps and action plans when necessary
- More explanation about underlying principle of this framework is available in TU Delft education repository and search for thesis Savitri Dinar Wulandari

Follow these following steps to use the Innov-Infra Framework:

1. Start from Part I, top left corner "**Clarify the following innovation boundaries for (multi) projects**"
   Ensure these factors are presence and clear in your projects/programme. These are the boundary conditions for innovations in (multi)projects. Assign responsible persons to the presence of innovation boundary. For example, Management team or programme manager.
2. Move to step **1. Create awareness about innovation process** and Step **2. Developing basic knowledge of the latest technology trends**
   Ensure the action plans are fulfilled to facilitate the development and implementation of innovations. When the action plan is not applicable to organization, ensure alternative plans are created to generate the desirable outcome. For example, action plan "1.1 Sharing lesson learned of innovation development internal organization and in professional knowledge sharing network". When the organization does not have experience in projects with innovations, other alternative action plan can be inviting other organizations to share their experience on innovation development.
3. Move to Part II Step 3, 4, and 5 and choose the action plans depending on organization.
   It is not necessary to follow the order of step 3,4,5 but following the order of action plan per step is preferred.
   For example, a responsible person who leads the Innov-Infra process from an Engineering company chooses step 4. Programme/projects procurement as the first step in Part II. The action plan "4.1 Negotiate term and conditions on the contract to avoid disruption on innovation process (consider innovation boundary in Part I)" must be first followed before moving to action plan "4.2 Advising the client about the choice of collaboration form to promote innovation during market consultations/ discussion points with clients".
   Ensure each action plan is assigned to a responsible person(s).
4. Ensure all the steps in Part II are followed and action plans are completed. When the action plan is not applicable to organization, ensure a replacement of action plan is made, assigned it to a responsible person, and complete the action.
5. It is recommended for organization to organize a regular review of utilization Innov-Infra depending on the intensity of the projects/programme i.e Bi-weekly or monthly.
6. When all steps are followed, it is recommended to re-do the process from Part I and Part II to ensure the steps and actions plan are still valid, especially in the long-term multi-projects.

Contents

List of Figures

List of Tables

List of Abbreviations

Abbreviation	Definition
BIM	Building Information Modeling
BQWP	Bridges and Quay Wall Programme
CoPs	Complex Product System
DTT	Digital Twin Technology
HPC	High Performance Concrete
IP	Innovation Partnerships
IPQ	Innovation Partnerships Quay wall
MC	Managing Contractor
MWW	Multi Water Works
OECD	Organisation for Economic Cooperation and Development
PMI	Project Management Institute
QWR	Quay Wall Renovation
R & D	Research and Development
RHDHV	Royal HasKoningDHV
RQ	Research Question
RTR	Road Tunnel Renovation Program
SAVE	Samen Amsterdamse kademuren Vernieuwen
SBIR	Small Business Innovation Research
SME	Small and Medium Enterprises
SRQ	Sub Research Question
TEC	Tunnel Engineering Consultant
TRL	Technology Readiness Level

List of Terminology

Terminology	Definition
Supplier	Any natural or legal person or public entity or consortium, of such persons and/or bodies, offering to supply products (EUComission, 2018) Suppliers in this research context are market parties/companies which include engineering companies and contractors
Stakeholders	An individual, group, or organization that may affect, be affected by, or perceive itself to be affected by a decision, activity, or outcome of a project, program, or portfolio (PMI, 2021) A stakeholder is an entity or individual who has something to gain or lose from the implementation of any phase of the program (Delaney, 2014)
Infrastructure	Infrastructure consist of existing facilities, equipment, organizational and telecommunications channels, information technology hardware, availability, and capacity. It is the system that provides essential services for society and the economy. The construction of infrastructure is commonly funded by public money
Contracting authorities	European Union, represented by the European Commission on behalf of and for the account of the beneficiary country/countries or the State or the entity concluding the contract as provided for (where appropriate) in the Financing Agreement (EUComission, 2018) The state, a province, a municipality, a water board, or a body governed by public law or an association of these authorities or bodies governed by public law Synonym: public client, government, commissioning authority
Internal stakeholder	Stakeholder from the internal public client organization
Innovation elements	These are elements that influence the innovation process, consisting of inputs, preconditions, drivers, enablers, barriers, outputs, and outcomes of innovations. It is also referred in this research as innovation boundaries
Preconditions	Something that must happen or be true before it is possible for something else to happen. In this research context, preconditions are preceding conditions, factors, or circumstances that have an influence on the innovation process
Output	Direct and measurable result of innovation process
Outcome	Impact resulting from the outputs
System integrator(s)	Principal contractors or designers (engineering companies) based on Winch (1998), who position themselves between clients and third parties, collectively organize the skills and translate demands from clients

1 Introduction

1.1. Background

The construction sector plays a critical role in building essential infrastructure and has a notable impact on the country's economy (Rijkswaterstaat, 2019). Being a significant stakeholder in the construction industry, the government encounters challenges in managing the increasing projects size and complexity, resulting from integrating societal goals such as reduction of Nitrogen and CO2 emissions, sustainability, and circularity. An example is a large-scale renovation and replacement of infrastructure assets in the Netherlands (Rijkswaterstaats, 2023b). These projects undoubtedly demand a substantial investment (Rijkswaterstaat, 2019; Debouwcampus, 2023). In addition, there is an increasing tendency for the outcomes of projects not to meet these goals or ambitions of the government (Frederiksen et al., 2021; Van Buuren et al., 2010). With the increasing dynamic of the construction industry, the project management approach has reached maturity and has apparent limitations (Shehu & Akintoye, 2009).

To address this major challenge, programme emerges to overcome the challenge to enhance productivity and facilitate the goals of society to the greatest extent possible. Programme management concentrates on managing a group of projects instead of focusing on individual projects. Programme has been recognized to generate benefits and opportunities for organizations, as well as a means to achieve organization objectives (Yan et al., 2019; Spijkerboer et al., 2015; Fathi et al., 2007). In the Netherlands, government bodies increasingly use programme to gain effectiveness and efficiency through the integration of multiple construction projects and deal with complexity (Van Buuren et al., 2010; Rijke et al., 2014). A shift in the policy is also observed where the focus on an individual project is expanded to a wider scale, the so-called programmatic approach (Spijkerboer et al., 2015). Not only beneficial to public clients, but programme also benefits suppliers where they can potentially develop and maintain new capabilities for the future, enabling innovation, expanding market share, and implementing companies renewal strategies (OGC, 2011). The programmatic approach attracts suppliers through incentives and long-term collaboration that is beneficial for both suppliers and the government as public clients (Xue et al., 2014).

Unlike other industries, infrastructure programme is unique because it deals with the coordination and integration of multiple projects environment, complex utilization of resources, long duration, and extensive stakeholders involvement of which the collective actions of these factors will result in achieving programmes objectives (Frederiksen et al., 2021; Van Buuren et al., 2010; Fathi et al., 2007). This uniqueness can be observed through its challenges, issues, and requirements for information and services to achieve the goals. Moreover, programme in infrastructure tends to happen for a long duration even ongoing (Thiry, 2004). Because of these complex activities and challenges, there is an obvious need to align, coordinate, and manage projects collectively to achieve benefits (Shehu & Akintoye, 2009).

Demand of innovation in infrastructure

Alongside the use of programmes, innovation becomes a prominent theme related to the infrastructure sector (Rijkswaterstaat, 2022; Spijkerboer et al., 2015). In general, innovation has been recognized to have a pivotal role in elevating the living standard and has a far-reaching effect on individuals, institutions, whole economic sectors, and nations (OECD & Eurostat, 2018). The Dutch government currently

faces challenges related to the technical lifetime of infrastructure assets, as well as societal challenges regarding sustainability and circularity. As a result, it is predicted that large-scale projects will continue to grow, and these projects require a significant budget from the government (Adriaanse, 2014; Arnoldussen et al., 2017; EIB, 2022). In addition, societal challenges such as circularity, sustainability, and nitrogen reduction shape the need for innovation at the national level (Bossink, 2004; Edquist and Zabala-Iturriagagoitia, 2012; Rijkswaterstaat, 2019; Koopmans, 2021). Innovation can facilitate the government to improve the quality of public service (Edquist and Zabala-Iturriagagoitia, 2012; Rijkswaterstaat, 2019). Innovation is therefore needed to not only accelerate the pace of activity in an effective and efficient way but also answer societal demand (Adriaanse, 2014; Arnoldussen et al., 2017;Koopmans, 2021).

In correlation with the infrastructure programme, innovation becomes a crucial factor. Innovation is needed to meet the governments objective to manage multiple infrastructure activities such as renovation and maintenance that increasingly become complex, by providing a smart, sustainable, and affordable solution. There is a strong intention for innovations from the government bodies in the Netherlands, such as Rijskwaterstaat and Municipalities because managing complex projects with environmental challenges can not be approached with traditional methods (Xue et al., 2014; Rijkswaterstaat, 2019). For a multi-project environment such as an infrastructure programme, to achieve effectiveness and efficiency, standardization of innovative solutions is needed for example in the renovation of multiple infrastructure assets. To achieve standardization, the innovation must be scalable, and its implementation shall be guaranteed through the repeatability of works (Rijkswaterstaat, 2022; Debouwcampus, 2023; Amsterdam, 2022; Spijkerboer et al., 2015). For the suppliers, innovation is needed at the project level to fulfill the requirements of the client and achieve the project goals through efficiency gain. While at the suppliers organization level, besides using innovation to reach efficiency and effectiveness, it is used to improve the organizations competitiveness (Sexton and Barrett, 2003; Dulaimi et al., 2005; Slaughter, 1998).

Innovation in infrastructure industry
The uniqueness of innovation in the industry is exemplified by the outcome it generates, particularly in the context of the Complex Product System (CoPS) (Winch, 1998). CoPS emerged as a consequence of the dynamic interplay among various actors involved in industry innovation. This system consists of interconnected elements that are customized and organized in a hierarchical manner, resulting from either a top-down or bottom-up approach to innovation. In the top-down approach, innovation is driven by the demands and needs of clients. Regulators play a crucial role in governing and regulating the innovation environment, ensuring that it aligns with societal and industry requirements. Professional institutions contribute by supplying knowledge and expertise on innovation, enabling actors in the industry to stay updated and make informed decisions. Conversely, the bottom-up approach to innovation involves contractors, specialist consultants, and their suppliers. They adopt and implement innovation resulting from research and development (R&D) efforts and external sources. Furthermore, these actors engage in a continuous learning process, drawing insights from problem-solving experiences encountered during projects. This multi-faceted approach to innovation reinforces the uniqueness of the industry. By considering both the top-down and bottom-up perspectives, a comprehensive environment of innovations emerges, where diverse actors collaborate and contribute to the development of CoPS. Such a system encourages creativity, fosters interdisciplinary collaboration, and enables the integration of various knowledge domains, ultimately driving progress in the industry (Winch, 1998).

Suppliers, although they own a lot of knowledge to innovate, often require investing a significant budget to innovate and face difficulty in reaching economic benefit. On the other side, the government as a public commissioner requires collaboration with the market to answer the societal challenge but within a constrained public fund to purchase innovative solutions. The interests and priorities of both stakeholders must be balanced to achieve successful outcomes in projects (Jarvenpaa et al., 2022; Lenderink et al., 2022; Vosman, 2020). It implies that innovation in infrastructure cannot simply rely on market pull from the government or push from the suppliers. Instead, conditions need to be created to facilitate interaction between actors, such as creating demands for innovations in government projects (Jarvenpaa et al., 2022; Rijkswaterstaat, 2022). Innovation in the programme, therefore, is twofold. Programme is seen as a means to attain innovation as the long-term goal of government, along with

other similar goals such as sustainability and circularity (Artto et al., 2009). By implementing innovation in multiple projects, the high investment made by suppliers can be distributed and the learning from each project can be immediately applied within programme (ProvinceNoordHolland, 2023; Debouwcampus, 2023). But innovation is also a vehicle to achieve the infrastructure programme goals, as argued earlier, due to the increasing complexity and size of infrastructure projects and to meet societal demands.

1.2. Problem Definition

Although desirable, the government approach to innovation within programmes to improve effectiveness is not widely used in the Netherlands (Debouwcampus, 2023; Rijkswaterstaat, 2022; Spijkerboer et al., 2015). It results in not many governments body being experienced with the programming process as well as maximizing its potential to integrate innovation into the programme. This induces several issues in relation to the implementation of innovation in programme. Firstly, as a result of unfamiliarity with using a programmatic approach due to a lack of concepts, rationales, and approaches to stimulate innovation within programme, the project-based approach is still used as an approach to purchase and manage innovations. This project-based approach becomes problematic because it is associated with strict requirements, shorter time-bound (to deliver projects), inappropriate incentives, and high uncertainty inherent to project and innovation which hinder the innovation, while innovation has an uncertain character that requires time and flexibility (Volker, 2019; Vosman, 2020; Lenderink et al., 2022). Secondly, even if the innovation is utilized in the project, continuity, and scalability are lacking (Volker, 2019; Rijkswaterstaat, 2022). This is because, in practice, the innovation is only used until at the scale of a pilot project. Once the pilot project is completed, there is a lack of certainty related to the adaptation issue of the innovation, procurement of innovation, unclear benefit, risk management, or changes in organization (Rijkswaterstaat, 2022). Meanwhile, innovation and standardization are crucial factors for the programmatic approach (Rijkswaterstaat, 2022). Moreover, the learning curve is less progressive when projects lack interconnection because the knowledge is dispersed once the projects end (Rutten et al., 2009). Third, the dilemma of innovation is constantly faced by suppliers in the project-based approach, meanwhile, the involvement of suppliers is highly needed in the implementation of the programme (Debouwcampus, 2023). This is mainly related to the incentive and high investment that occurs to develop innovation. Even though innovations are intended in the projects within programme, the uncertainty of work still occurs as a result of changes on programme's level.

These problems result in the utilization of innovation in the multi-project settings not being optimum due to the limitation inherent in the project-based approach in the infrastructure programme. The innovation capability of suppliers is not fully utilized to reach high productivity and to gain efficiency and effectiveness in programme (Vosman et al., 2023). These limitations encompass an inadequate understanding of innovation and programme, a lack of progressive learning curve, and a dilemma to develop and implement innovations in projects are the result of a project-based approach. This condition raises questions about the programme's pre-conditions to stimulate innovation. What are the motivations of clients to demand innovations in programmes and what conditions are needed to innovate? What kind of involvement is required from the suppliers and clients to ensure programmes success?

Although a few numbers of literature have indicated that development and implementation innovation on a larger scale can be highly supported through programme (Frederiksen et al., 2021; Arnoldussen et al., 2017), empirical research about the relation between innovation with programme remains scarce. Moreover, the majority of this pool of literature focuses only on the perspective of a public client. It is undeniable that collaboration with the market participants is needed. This research aims to investigate the potential use of innovation within the infrastructure programme in the Netherlands and how it can be fostered by looking at the perspective of suppliers as market participants. It is because, as argued above, the suppliers' role, especially in the bottom-up approach is crucial to accelerate the progress of the infrastructure programme through innovation. The suppliers' own knowledge and capability to innovate but innovation progress is hindered due to the project-based approach. The central focus of this research is innovations in multi-projects within the infrastructure programme.

1.3. Research Objective

Innovation in the construction industry occurs due to the interplay of various actors (Winch1998). Despite a clear benefit of innovations in infrastructure programme, the relationship between innovation and programme receives minor attention and lack practicality. This research aims to enhance understanding of the factors and mechanisms that play a crucial role in the further development and implementation of innovations in the multi-projects as part of the infrastructure programmes by looking at the perspective of suppliers. Furthermore, through the findings of this research, a framework is developed, to guide the development and implementation of innovations in the infrastructure programme.

1.4. Research Question and Sub-Research Questions

Based on the research objective, the following research question is formulated to achieve the research objective:

How can innovations be facilitated in a multi-project setting, in order to contribute to the achievement of programmes' goals?

Sub-research questions (SRQ) are defined to get all the necessary input to answer the main research question. The sub-research questions are:

- SRQ1. What are the goals and characteristics of infrastructure programmes?
- SRQ2. What are the contributions of innovations in the infrastructure programmes?
- SRQ3. What are the barriers and enablers to innovations based on the literature?
- SRQ4. What are the barriers and enablers to innovations identified in programmes?
- SRQ5. What procedure can be applied by suppliers and public clients to facilitate the development and implementation of innovations in multi-projects?

1.5. Research design

This section delves into the research design, starting with the research scope, and subsequently followed by the research methodology.

1.5.1. Research Scope

Defining a research scope is crucial to set the research boundaries and determine what is included and excluded due to the vast array of potential topics.

- This research specifically examines infrastructure programmes in the Netherlands with a particular emphasis on innovations that are found at the (multi) project level
- This research includes process and/or product innovations in infrastructure whether it is incremental innovation, substantial, or radical innovation based on the categorization from the literature (Lenderink et al., 2022; Garcia and Calantone, 2002). Product innovation in this research context is an innovative solution, that leads to a substantial improvement in the functionality, the extension of the functionality, and/or the improvement of the technical performance of an infrastructure object whereas process innovation is an innovative solution to increase the efficiency of the construction process (Lenderink et al., 2022). To identify these projects, the projects/programme procurement framework for innovation-encouraging by Lenderink et al. (2020) is used, where three types of procurements for innovations are indicated: regular procurement (innovation-friendly), innovation-oriented, and innovation-driven programme.
- This research focuses on examining how suppliers, including principal contractors, engineering and consultancy companies, and their supply chains, contribute to the development and implementation of innovations in multi-projects. These suppliers play a vital role in achieving programme objectives, making their perspective a key area of investigation.

Consultancy company as a system integrator

According to Winch (1998), engineering companies in the construction industry assume a vital role as system integrators during the innovation process. The term system integrator is commonly used in Complex Products and Systems (CoPS), where a company strategically establishes a network of

organizations and oversees the integration of resources from network members. Ideally, the system integrator's skills and knowledge enable them to effectively set up and coordinate innovation, thus assuming responsibility for the system's functioning and project-based production (Rutten et al., 2009; Winch, 1998). As a project-based organization, the company produces innovation within a project context by utilizing the knowledge from one project to another and highly depending on a coalition with its client and supply chain (Gann and Salter, 2000; Ozorhon and Oral, 2017). This interaction with partners and the supply chain, results in various degrees of innovation at the project's level and company, varying from incremental to radical innovation, depending on the project context (Rutten et al., 2009). The company's approach to innovation dominantly operates using a reactive approach because innovation is developed based on the knowledge from past projects and the company seeks continuity in future projects (Gann and Salter, 2000; Cantarelli and Genovese, 2021).

1.5.2. Research methodology

This research comprises four primary phases to achieve the research objectives starting with theoretical phases. In the first phase, a literature review is conducted to build a sufficient theoretical foundation to build the methodology for this research. The second phase is an empirical phase, where analysis of case documentation, and interviews of the selected study cases are performed. The findings are used as input for a solution's framework before being validated by the experts in the third phase. In the finalizing phase, discussion, conclusions, and recommendations are presented.

Phase I: Theoretical phase

As the initial phase of this thesis research involves creating a thesis proposal, a preliminary literature study was conducted with the purpose of establishing a theoretical foundation for the research proposal and connecting it with the practical problem concerning innovations and programmes. In order to develop a comprehensive proposal, information from literature related to programmes and innovations was integrated with findings from public sources. Since there is a lack of adequate literature on infrastructure programs, in-depth qualitative research is chosen for this research to explore the subject thoroughly. The research company where this thesis research was conducted was already chosen in the early stage of the research. Because of this, early indications of the case studies were identified within the company's project. This step leads to a clear definition of the problem and the formulation of research questions and sub-research questions (SRQs). In addition, because the research question is a 'how' question and focuses on contemporary events, a case study method is chosen as a suitable method for this research (Yin, 2009).

Following the research preparation, the topics investigated in the preliminary literature study were further explored to develop an understanding of the programmes and innovation process. Three main streams of literature were explored, which are programme, innovation, and innovation process, using specific keywords, as indicated in Appendix A. This phase predominantly involved desk research and helped to answer the sub-research questions through theoretical perspectives based on existing material, and finally build a theoretical framework. Since there is a limited amount of literature specifically focused on innovation in programmes, generalization is made based on project context. The chosen keywords are searched within multiple scientific sources such as TU Delft depository, Scopus, Research Gate, and Google Scholar. The use of keywords, both separately and in combination, facilitates the retrieval of relevant literature and research. Additionally, a snowball method and citation searching are employed to narrow down the search to more specific topics, such as innovation in programs, after identifying key publications. The results of the literature review are: first, it helped to refine the scope of this research and aid in choosing an appropriate methodology. Appendix A provides further details about the steps involved in a literature review. Second, it helped with the answer of SRQ 1,2,3. Third, a theoretical framework for innovations in programme including the innovation elements was built. The innovation elements are influential factors in innovations: drivers, preconditions, inputs, enablers, barriers, output, and outcomes of innovations.

Phase II: Empirical - Case study result and analysis

After completing Phase I, the findings are utilized as input for Phase II. The objective of this phase is to gain an understanding of the innovation process in practice and identify the barriers and enablers to innovations seen in the infrastructure programme. The main data source for this research is multiple

case studies from projects within programmes. Knowing that the topic of innovation within programme is relatively new, in-depth, and qualitative research has opted to study a small-scale approach before generalization is made (Verschuren and Doorewaard, 2010; Creswell, 2014).

The process of finding appropriate case studies used the theory gained from Phase I. The case study selection process can be found in Chapter 3. This phase involves gathering and reviewing case studies from project documents and conducting semi-structured interviews. The documents analyzed in this research are sourced from internal companies, such as tender and project documents, and external company data such as program documents from public clients. The related personnel to the case study were interviewed through a semi-structured interview approach and their selection is based on pre-defined criteria. A semi-structured interview is chosen in this research to allow follow-up questions based on the responses of the interviewees. The protocol of the interview can be found in Appendix D. In total 11 interviews were conducted before finally being examined and analyzed using the thematic analysis method. Through coding, common patterns and relationships between variables were identified. The output of this phase provides an understanding of the innovation process in multi-projects, including the impact of innovations in the infrastructure programme. A list of barriers and enablers to develop and implement innovations in multi-projects in practice together with the innovation elements was produced.

Phase III: Framework development
Using data collected from case study analysis, a set of recommendations was proposed, and a preliminary framework for the development and implementation of innovation in infrastructure programme was created based on the existing knowledge gained from the literature study and empirical findings of the case study. The purpose of the framework is to offer a structured approach to innovations that can be used in practice by suppliers and public clients for the upcoming infrastructure programme. This framework shall reflect the supplier's level of influence on the infrastructure programme as well as the role of public clients. To maintain the quality of the research, the preliminary framework was validated by experts from companies and public clients to ensure its relevance, credibility, and applicability to practice. A discussion during the experts' session allowed the identification of barriers, enablers, or solutions that have not been observed in the case study. Based on the output of expert evaluation, the framework was refined and finalized before finally being presented as a final framework, and a satisfying answer to SRQ5 was provided.

Phase IV: Finalizing
At the last phase of the research, based on the output of the previous phase, a discussion section was conducted at this phase. This discussion includes a comparison between empirical results and the theoretical background. The limitation of this research was presented in this phase. By the end of Phase IV, the conclusions were provided, by answering the main research question and all sub-research questions. A set of recommendations were presented and marked the end of this research.

1.5.3. Quality of the research design
Reliability and validity are part of the research design in order to produce a high-quality research outcome (Yin, 2009).

- Reliability of this research is maintained when the data collection procedure can be repeated and result in the same output. This is done by organizing the case study by developing a case study protocol and creating a database
- Validity includes construct validity by using multiple sources of data to identify correct operational measures of the concept being studied. The theoretical and empirical part of this research demonstrates this type of validity. In addition, internal and external validity are employed to establish whether a cause relationship in this result is valid and to define the domain to which a study's findings can be generalized.

Reliability and validity of this research are discussed in Chapter 6.

1.6. Research relevance

This research will contribute practical, scientific, and societal relevance to the existing knowledge not only about a programme and innovation in the infrastructure sector but also the combination of both.

1.6.1. Practical Relevance

This research aims for a deeper understanding of the development and implementation of innovation in the infrastructure programme and the specific challenges of innovations. The framework results from this research provide a guideline to facilitate innovation in the multi-projects as part of programme. Since this research is conducted in an engineering company, whose role can be as an advisor to the public clients, as well as the designer, the knowledge that comes from this research is potentially expanding the knowledge about managing, advising, executing programmes, and strategically innovating within programmes. It potentially enriches the knowledge of key roles in the organization such as senior managers, project managers, and technical managers. Especially, with the increasing number of infrastructure renovation projects, an understanding of the topic is valuable to improve practice in the organization. In addition, with the set of suggestions for public clients, this research potentially will be useful for key positions in public organizations such as programme manager, procurement and contract manager, tender manager, and project manager.

1.6.2. Scientific Relevance

While the concepts of programmes, have been discussed in the literature, there is still limited research on the relationship between programmes and innovation in infrastructure projects. This condition is observed based on the limited result of a literature search using a combination of programme or programme management and innovation. The majority of the literature is concentrated on the innovation aspects of projects as well as focusing on public clients' perspectives. This suggests that the topic of innovation and its contribution and impact on programme remains sacred. In addition, there is a lack of understanding of how to effectively stimulate innovation within programmes and how the market parties react to these demands. The outcome of this research will therefore provide a contribution to the body of knowledge.

1.6.3. Social Relevance

The challenge of managing programmes and innovations of infrastructure programmes falls on the public clients and current practices in this area are inadequate. In the future, society will face more complex challenges such as sustainability and circularity, and approaching them with a traditional project approach will not be sufficient. Through programmes, these challenges will be more likely addressed by recognizing the barriers and influence enablers to facilitate innovation in the infrastructure sector by incorporating societal demand. Thus, the complication in relation to the innovation that occurred within programmes must be dealt with.

1.7. Thesis outline

This thesis is structured based on the four phases of research design as explained in the subsection Research Design. The first phase involves a theoretical phase for the research including the Chapter 1 introduction section, followed by Chapter 2 theoretical background where a literature study on programme, innovations, and innovation processes are conducted. Based on the literature study, Chapter 3 describes the case study preparation and data analysis methods. Next, Chapter 4 Case study results and analysis involves conducting in-depth case studies of three programme cases to gather factual knowledge. To gain an understanding of the barriers and enablers of innovations in infrastructure programme, case study documents are analyzed and interviews with the suppliers are conducted. The findings of the case study are used to build a framework in Chapter 5 which contains a set of recommendations to facilitate innovations in programme. Expert evaluation is conducted in this chapter. In Chapter 6, a discussion about this research is conducted and it is followed by providing research limitations. Chapter 7, Conclusion and Recommendation involves answering the main research question before finally providing a final framework, a conclusion, and addressing the future research recommendations.

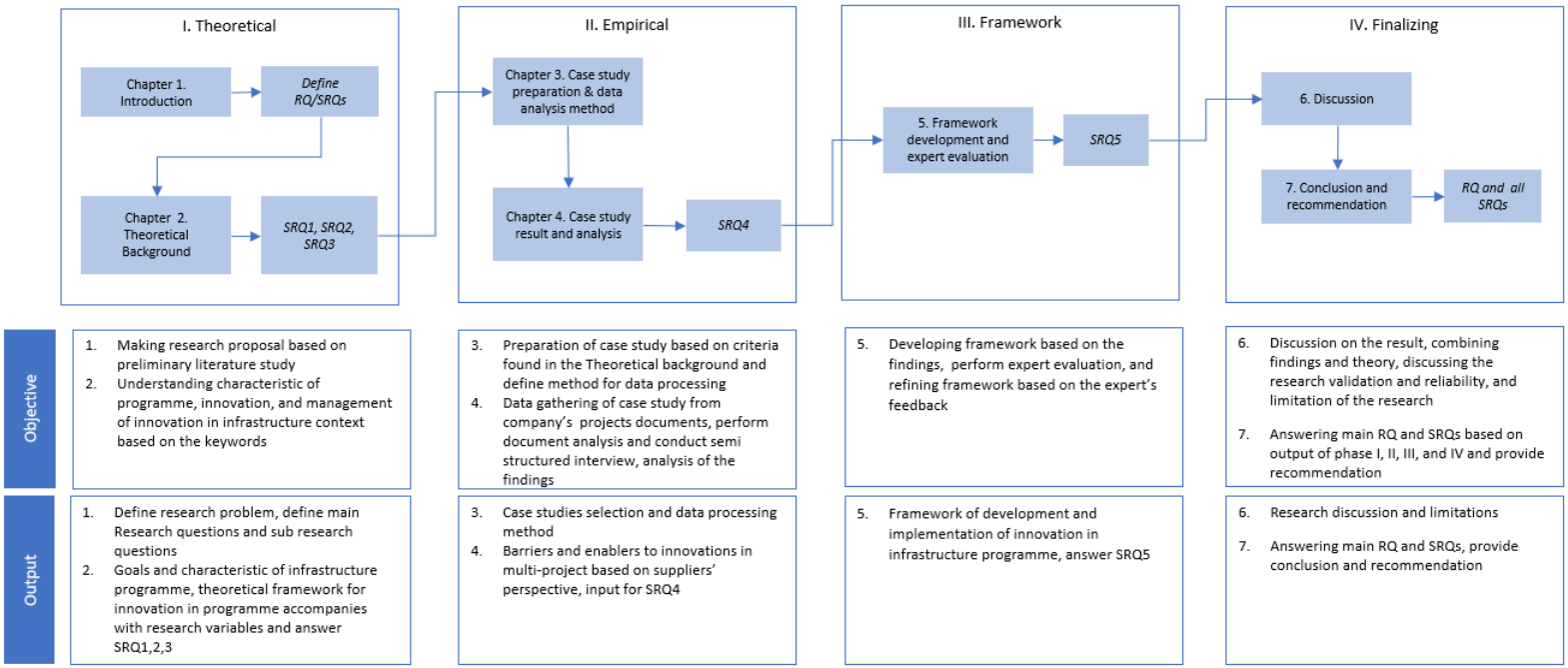

Figure 1.1: Thesis outline

2
Theoretical Background

The purpose of this section is to establish a scientific foundation upon which the research question and sub-research questions will be answered. As has been briefly mentioned in Chapter 1, the literature review is based on three streams of literature: programme, innovation, and management of innovation. This chapter, therefore, is built based on these three subjects. Section 2.1 focus on the theoretical background of programme before identifying the characteristic and life cycle of programme in infrastructure. Section 2.2 establish the innovation and its categorization before narrowing it down to infrastructure context by aligning various innovation concept in Section 2.3. The barriers and enablers to innovation will be discussed in Section 2.4. Then section 2.5 focuses on the public procurement for innovation in the infrastructure sector. The theoretical background examined in this section will be cross-checked and combined with the empirical data in the result section. In Section 2.6, a preliminary framework of innovation development and implementation in programme is drawn based on the findings in the literature.

2.1. Programme in infrastructure

2.1.1. Programme definition

Before going into the detail of the infrastructure programme, it is important to align the definition of programme, the type of programmes, and the difference between programme, projects, and portfolio. It is because the word programme is often used interchangeably with other terminology such as multi-project, portfolio of projects, project networks, and new business approach (Shehu & Akintoye, 2009).

According to the Project Management Institute (PMI), a program refers to a collection of interconnected projects, sub-programs, and program activities that are coordinated and managed together to achieve advantages that cannot be attained by managing them independently (PMI, 2021). This definition is aligned with definition by a number of literature which argue that programme focuses on the realization of benefits/goals/value of an organization as a common purpose, therefore, projects are managed in a coordinated way (Pellegrinelli, 1997; Murray-Webster and Thiry, 2000; Thiry, 2004; Blismas et al., 2004; Martinsuo and Lehtonen, 2007; Frederiksen et al., 2021). Programme is typically ongoing for the long term and therefore subject to uncertainty (Blismas et al., 2004; Turner et al., 1999).

Programme facilitates effective resource utilization, risk management, and stakeholder engagement across multiple projects (Pellegrinelli, 1997; Lycett et al., 2004; Shehu and Akintoye, 2009). However, programme is more than just sharing resource management of a group of projects, they form interactions among each other to effectively deliver multiple projects (Blismas et al., 2004; Lycett et al., 2004; Shehu and Akintoye, 2009). The interconnected projects, that runs parallel or sequential, facilitate knowledge transfers (Lycett et al., 2004). Effective delivery of projects is achieved due to better resource coordination, planning, and prioritization of projects (Pellegrinelli, 1997; Lycett et al., 2004; Shehu and Akintoye, 2009). Based on the above-mentioned characteristic, the definition of programme is better suited as an integrated, structured framework that co-ordinates, aligns and allocates resources, and plans executes and manages a number of related construction projects to achieve optimum benefits that cannot be realized if the projects are managed separately (Shehu and Akintoye, 2010; Shehu and Akintoye, 2009).

Programme is suitable for managing and coordinating a group of inter-related projects that are aligned with the organizations strategic objective (Pellegrinelli, 1997; Rijke et al., 2014). Programme can be also initiated based on the combination of various drivers such as economic reasons, to improve services, to expand collaboration, or to manage organizational change (Lycett et al., 2004; Shehu and Akintoye, 2009; OGC, 2011; Martinsuo and Hoverfallt, 2018; Frederiksen et al., 2021). Literature suggests that that programme is suitable to deal with complex challenges and long transformational changes such as sustainability and circularity. Although programme is subject to uncertainty, it owns an adaptive characteristic which suggests it is a good means to deal with flexibility and ambiguity that usually occur in transformational challenges (Pollack and Anichenko, 2022; Rijke et al., 2014). This suggests that a programme can be selected as a means of organizing multiple and complex projects in infrastructure that seek to address intricate societal needs.

Position of projects, programmes, and portfolio relative to organization
Following the above definition of programme, a clear difference must be made between programme and portfolio. A portfolio is defined as a total set of programmes and stand-alone projects undertaken by an organization that shares resources (Geraldi et al., 2022; PMI, 2021; Nicholas and Steyn, 2017). Although programme and portfolio management as a mode of organizing have similarities in terms of implementing and controlling multiple projects in parallel, the portfolio takes into account all areas of organizational benefit and links to the organizational goals (Geraldi et al., 2022). On the other hand, the scope of a programme is limited and does not take into account the entire organization's vision (OGC, 2011; Martinsuo and Hoverfallt, 2018; PMI, 2021; Pollack and Anichenko, 2022). It emphasized that portfolio management is more related to leadership and goal alignment of an organization that is usually solid while programme has a more adaptive character (Geraldi et al., 2022; Thiry, 2002). Programme has a specific start and end point whereas portfolio has a more continuous nature in the organization, without distinctive ends (Martinsuo and Hoverfallt, 2018; PMI, 2021;Geraldi et al., 2022). A project, as a temporary organization, delivers a distinctive product, service, or outcome, can be self-contained or form a part of programme or portfolio (Nicholas & Steyn, 2017). It means that the duration of projects is relatively shorter in comparison with programme (Delaney, 2014; Pollack and Anichenko, 2022). While programme focuses more on connectivity between projects, projects in the portfolio are not necessarily related to each other (Geraldi et al., 2022; PMI, 2021; Nicholas and Steyn, 2017).

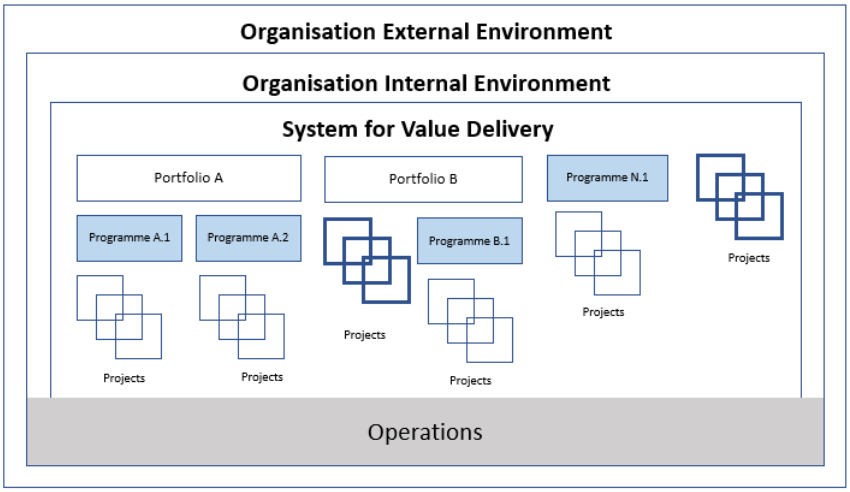

Figure 2.1: Position of projects, programmes, and portfolio relative to organization modified from PMI (2021) (Own figure)

The Figure 2.1 visualizes the position of projects, programme, and portfolios relative to organization based on PMI (2021). A system value inside an organization, consisting of interconnected projects, programmes, portfolios, and operations, aims to deliver value and is aligned with the organizations strategy (PMI, 2021). Projects under programme are interrelated, and a group of programmes can be part of a portfolio, such as depicted under Portfolio A in Figure 2.1. Programme can be also stand-alone

and not part of a portfolio. Multi-projects under the portfolio are not necessarily related and together with another set of programme can be part of a portfolio. While it is also possible that multi-projects are stand-alone in the organization and are not part of a portfolio or programme. As seen in Figure 2.1, an organization uses portfolios, programme, projects, and operations collectively or individually to create value that aligns with the organization's strategy under a system for value delivery. This system is an integral component of an organization's internal environment, encompassing policies, procedures, methodologies, frameworks, and governance structures. This internal environment operates within the broader external environment, which encompasses factors such as the economy, competitive landscape, and legislative constraints (PMI, 2021).

As one of the ways to realize an organization strategy, programme requires to be adaptive as outcomes of the projects are achieved (PMI, 2021; Delaney, 2014; Pollack and Anichenko, 2022). In this case, project and programme shall be considered as two approaches that could benefit and influence from one to another (Shehu and Akintoye, 2009; PMI, 2021; Van Buuren et al., 2010). As two approaches opting towards the intended end, projects, and programme management remain related because programmes consist of projects and the success of projects will determine programmes success (Yan et al., 2019).

In addition to portfolio, programme is often confused with the term multi-project. Multi-project environment is simply used to emphasize the multiplicity of projects in an organization which may not be as well conveyed using the term portfolio (Blismas et al., 2004, p. 359). In contrast with the definition of programme, the projects in the management of multi-project are not interrelated or serve a common purpose. Programme management encompasses a much broader scope than traditional resource management (Pellegrinelli, 1997). Although the interchangeable use of programme and multi-projects remains in the practice, in the context of this research multi-projects still be referred to as a group of interrelated projects.

The table below summarizes the key differences between projects, programmes, and portfolios based on literature. The main difference between the three is the objectives. A portfolio focus on the management of groups of projects, programmes, and operations. While programme focuses on creating value through interrelated projects that can not be created by managing an individual project. The project concentrates on delivering unique products/services/results. Projects, programmes, and portfolios mutually impact one another (PMI, 2021).

Table 2.1: Major difference between programme and projects (Pollack and Anichenko, 2022; Sanchez et al., 2009; Thiry, 2004; Pellegrinelli, 1997) (Own table)

Indication	Portfolio	Programmes	Projects
Objective	Effective management group of projects, programmes, and operations, to meet strategic objectives	Aiming for far-reaching outcomes, create value, and maximize benefits through a collection of projects	Focus on delivering unique products, services, and results
Time span	Long and/or indefinite duration, no life cycle	Longer than projects, depending on life cycle	Short and limited duration, based on project life cycle
Organizational Approach	Mix transformational change managed through process	Transformational change managed through process	Traditional way
Outcome	Mix iterative and sequential delivery	Iterative delivery	Sequential delivery
Attitude to change	Open and adaptable, Uncertainty acceptance	Open and adaptable, Uncertainty acceptance	Isolated and inflexible, Uncertainty control
Attitude to ambiguity	Uncertainty acceptance	Uncertainty acceptance	Uncertainty control approach (predict and control)
Focus on deliverable	Maximize portfolio value, balance the portfolio, align projects/programme towards organization's strategic goal	Effective deliverable of organizational value and benefit	Efficient delivery of product
Communication approach	Portfolio managers organize the interaction of projects and/or programme under portfolio	Programme manager facilitates the interaction of numerous managers	Project manager has single point responsibility for projects success

2.1.2. Programme categorization

Now that the definition of programme is clear, it is also important to understand that programme occurs in various forms and often in a mixed form (Pellegrinelli, 1997; OGC, 2011). Understanding programme types and their influences upon them form a significant contribution to the management approach and the result of programmes (Blismas et al., 2004; Lycett et al., 2004; Van Buuren et al., 2010). The categorization of programme based on various literature is depicted in Table 2.2. These various categorizations help to identify the type of programme in infrastructure and help identify the case selection for this research.

Table 2.2: Summary of programme type based on various literature (Own table)

Literature source	Programme category
Pellegrinelli (1997)	(1) Portfolio (2) Goal-oriented (3) Heartbeat
Van Buuren et al. (2010)	(1) Type 1light coordination (2) Type 2 Shared service (3) Type 3 integrated development
OGC (2011)	(1) Vision-Led programme (2) Emergent programme (3) Compliance programme

Pellegrinelli (1997) suggests that the programme can be categorized into three groups based on the coordinating benefits sought by the programme: portfolio, goal-oriented, and heartbeat. As it has been mentioned in the previous section, a portfolio focuses on the utilization of resources, knowledge, and skill by grouping projects that are relatively independent of one another. Van Buuren et al. (2010) has similar categorization to this type where programme focuses on coordination mechanism (type 1) and acts as a shared service for projects (type 2) to achieve organization efficiency. Similarly, OGC (2011) uses the term emergent programme to describe this necessity to coordinate projects to deliver a desired benefit. The second category of programme from Pellegrinelli (1997) is a goal-oriented programme. The goal-oriented programme enables the management of initiatives or development outside the existing infrastructure or routine. This has overlap with the type 3 programme from Van Buuren et al. (2010) and the vision-led programme from OGC (2011) that is concerned with the integration of an organizations strategy. The third category from Pellegrinelli (1997) is the heartbeat programme that typically facilitates ongoing enhancements to existing systems, infrastructure, or business processes through incremental updates or, in some cases, a complete overhaul of the system or facility such as seen in IT sector. Another category originated from OGC (2011) is a compliance programme where the programme arises due to certain external changes such as legislative change. An organization is obligated to implement a compliance program, which is typically seen in government bodies. The benefit of this program is usually evaluated based on the accomplishment of compliance and prevention of negative outcomes, rather than measurable enhancements in performance (OGC, 2011). In this research, the focus is given to the categorization based on OGC (2011).

2.1.3. Programme lifecycle

Being a changing agent of changes in an organization, programme life cycle resembles a change process (Martinsuo & Hoverfallt, 2018). In general, programme life cycle can be distinguished into initiation, implementation, renewal, and dissolution phases. Programme has similarity to a projects life cycle, but the difference is programme life cycle run in a cyclical and iterative rather than linear where it can be linked to an organization's yearly cycles or learning cycle (Pellegrinelli, 1997; Thiry, 2002 PMI, 2021; Martinsuo and Hoverfallt, 2018).

- Programme initiation signifies the beginning of a program, which involves programme identification and creating the program's definition, and assembling the programme team, before defining the programme objective and responsibility (Pellegrinelli, 1997; Lycett et al., 2004; OGC, 2011). At this phase, the expectations of stakeholders are identified and projects are defined.
- Programme implementation is the next stage of programme life cycle (Pellegrinelli, 1997). It is where the actual initiation of projects, begins with programme procurement process (Grandia and Volker, 2023; Lutt, 2021) and follows with the execution and delivery of projects. The benefits and risks shall be managed to ensure the achievement of the final goal of the project (Lycett et al., 2004; OGC, 2011). Between the programme delivery and programme closure, renewal possibly occurs to validate the current conception of the programme (Pellegrinelli, 1997).

- Programme dissolution is indicated When the benefits of the programme are realized or the rationale of the programme is no longer valid (OGC, 2011) It is where a formal assessment of the programme is included (Thiry, 2004; Lycett et al., 2004). The assessment contains a performance-based loop and learning element (Murray-Webster & Thiry, 2000).

The overview of the programme life-cycle is illustrated in Figure 2.2 below.

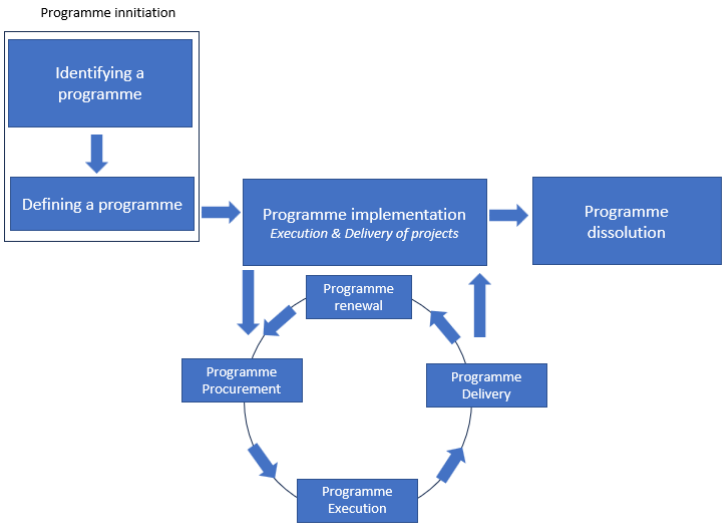

Figure 2.2: Simplified version of programme life cycle based on OGC (2011) (Own figure)

It is agreed among the literature that the early stage of programme, which refers to programme identification, programme definitions, and formulation, is crucial to setting up strategy and scope (Pellegrinelli et al., 2007; Thiry, 2004; Martinsuo and Hoverfallt, 2018). This is where the sense-making of the programme occurs and stakeholders commit and support the programme to establish a realistic plan (Martinsuo and Hoverfallt, 2018; Rijke et al., 2014). For the development and implementation of innovation within projects in programme, the focus will be given to the early phase and the implementation phase of the infrastructure programme.

Challenges can be experienced during the adoption, implementation, and execution of programme. To ensure the successful implementation of programme management, Shehu and Akintoye (2010) proposes six stages that consist of unawareness to awareness, understanding, programme planning, piloting, implementation, and customization and consolidation, as illustrated in the Figure below.

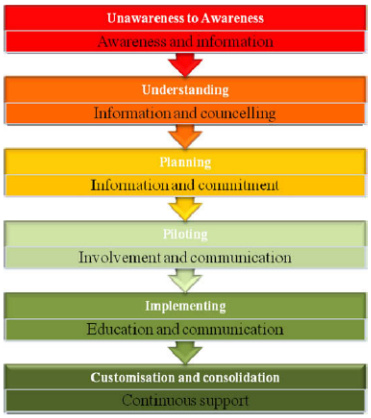

Figure 2.3: Framework for effective implementation of programme management by Shehu and Akintoye (2010)

The framework above illustrates that at every stage, supports are available to overcome challenges

(Shehu, 2008; Shehu and Akintoye, 2010). As an example, in the unawareness to awareness stage, awareness and information are needed to gather support and educate about programme. In the understanding stage, the aspects of programme need to be understood which include major challenges, critical success factors, skills, and competencies. Programme planning is a critical stage that lays the ground for programme and contribute to the success of execution. In the pilot stage, a selected project is performed in an isolated environment to gather information and insight before larger resources are further deployed. Once the pilot succeeds, the implementation stage starts. In the customization and consolidation phase, the organization can fully adopt the programme management approach that is suitable for the organization. By undergoing this process, the organization has a clear vision of the programme benefits. In relation to this research, this framework is utilized to make a relation between the programme and the development and implementation of innovations.

2.1.4. Goals and characteristics of infrastructure programme

Now that the basic understanding of programme has been discussed, the goal and characteristics of the infrastructure programme can be identified. To be able to identify the goal and characteristics of the infrastructure programme, a set of literature discussing programme in infrastructure are reviewed to provide relevance to the topic. This literature can be seen in Table 2.3 below.

Table 2.3: Inventory of reviewed literature in infrastructure programme (Own table)

Authors	Client/country/context	Subject of research
Frederiksen et al. (2021)	Denmark	Construction programme of educational and day care facilities in Denmark
Hertogh et al. (2018)	The Netherlands	Life Cycle Management of infrastructure using programmatic approach
Rijke et al. (2014)	The Netherlands	Renovation and maintenance of dikes and water infrastructure in the Netherlands
Delaney (2014)	US	Construction program management
Pellegrinelli (1997)		Infrastructure in IT
Shehu and Akintoye (2009)	UK	UK Construction industry
Y. Liu et al. (2019)	The Netherlands	Infrastructure renovation programme for the replacement and renovation of 52 ship locks over the next 30 years in the Netherlands
Yan et al. (2019)	China	Success criteria in construction program management
EIB (2022)	The Netherlands	Programme and innovation in infrastructure
Tromp et al. (2022)	The Netherlands	Dutch flood protection programme

Goals of infrastructure programme

Similar to projects, each infrastructure programme is a unique endeavour. Infrastructure assets are generally managed by public organizations, programme in infrastructure are, therefore, led by a certain need for compliance, such as to provide safe and reliable infrastructure (Hertogh et al., 2018; Tromp et al., 2022). This becomes the primary goal for a programme's creation in infrastructure. A primary goal focuses on the functionality of the infrastructure assets to ensure the availability of the assets to the users (Spijkerboer et al., 2015; Hertogh et al., 2018). This goal is usually clearly articulated by the public organization as the owners of the assets and this goal becomes the main driver of programme's creation, such as seen in the River Widening programme (Rijke et al., 2014) and infrastructure renovation programme (Hertogh et al., 2018). On top of compliance, the government has ambitions or visions to achieve a certain quality standard of infrastructure and fulfil societal goals such as sustainability and circularity (Spijkerboer et al., 2015; Van der Vlist et al., 2016). This makes an infrastructure programme a means to fulfill the strategic objective of the government (Shehu and Akintoye, 2009; Eweje et al., 2012; Trzeciak et al., 2022) and is categorized as a vision-led programme. An example is a high-quality regional development is achieved as a result of a programme (Van Buuren et al., 2010).

In addition to the main goal of the infrastructure programme, an opportunity to add value may arise (Rijke et al., 2014; Hertogh et al., 2018). As seen in the infrastructure renovation programme, the opportunity arises to improve the existing infrastructure that typically only has a single function. As an example, during the renovation of flood defenses as part of the Dutch Flood Protection Programme

(DFPP), an opportunity arose to create a multi-functional flood defense that combined with improvement of spatial quality and taking into account the environmental aspects (Rijke et al., 2014; Hertogh et al., 2018). This opportunity becomes the secondary goal of the programme. Besides the presence of added value as a secondary goal, the conditional goal can be also seen in the infrastructure programme. A conditional goal needs to be fulfilled in order to achieve the primary goal (Bindelrs, 2021). As an example, innovation is a secondary goal of a programme because innovation helps to deliver the necessary action to reach the efficiency and effectiveness of the programme (Tromp et al., 2022). Although these two types of secondary goals are similar, the main difference is the value-added goals do not influence the outcome of the primary goal while the conditional goal does (Bindelrs, 2021). According to OGC (2011), multiple goals can occur within programme as a result of the involvement of various stakeholders.

Characteristics of infrastructure programme
Based on the review of literature on infrastructure programme, there are ten characteristics of the infrastructure programme that can be delineated in the following :

1. Inter-related multiple infrastructure projects that are centrally coordinated by programme organization and integrated to achieve organizational benefits (Shehu and Akintoye, 2009; Delaney, 2014; Frederiksen et al., 2021)
2. Government-initiated programme in infrastructure can be vision-led or compliance-focused, aimed at meeting safety requirements, implementing strategies, changing business operations, and achieving the organizations strategy. A secondary goal/objective may arise such as to deliver added value (Rijke et al., 2014; Hertogh et al., 2018; Tromp et al., 2022; Y. Liu et al., 2019)
3. Infrastructure programmes involve large-scale, therefore, programme typically runs for extended duration allowing contextual changes and prioritizing flexibility and emergent strategies (Pellegrinelli et al., 2007; Van Buuren et al., 2010; Y. Liu et al., 2019; Frederiksen et al., 2021; Rijke et al., 2014)
4. Projects within infrastructure programmes share resources and can run parallel or sequentially (Shehu and Akintoye, 2009; Frederiksen et al., 2021; Pellegrinelli et al., 2007; Delaney, 2014)
5. Infrastructure programmes focus on stakeholders, benefits, and governance. Complexity arises from these three elements, as examples: technical and societal demand, limited budget, changing environment, and multiple stakeholders (Frederiksen et al., 2021; Rijke et al., 2014)
6. Infrastructure programmes have dedicated programme organizations that coordinate and collaboratively manage resources between projects within programme, distribute risks, and address the demands of multiple institutional environments (Shehu and Akintoye, 2009; Frederiksen et al., 2021)
7. Coopetition (cooperative competition) exists within infrastructure programmes, requiring cooperation among projects within programme to achieve mutual organizational and project objectives (Van Buuren et al., 2010)
8. Grouping projects helps to accelerate learning between projects (Shehu and Akintoye, 2009; Frederiksen et al., 2021; Pellegrinelli et al., 2007; Hertogh et al., 2018)
9. Infrastructure programmes follow an iterative life cycle and have a dynamic character based on learning, which enables organizational and project-level improvements (Tromp et al., 2022; Pellegrinelli et al., 2007)
10. Programmes in infrastructure facilitate innovation through cooperation, knowledge transfer, resources, and technology sharing (Tromp et al., 2022)

2.2. Innovation definition and categorization

Following the explanation of the program and its significance in Section 2.1, this section focuses on the rationale for utilizing innovation within the program. For a start, the definition of innovation and its various types will be established, before examining the innovation process in infrastructure programs. It is essential to note that the majority of literature on innovation is related to the construction industry, which encompasses infrastructure. Therefore, while this study examines innovation in the context of infrastructure, it can also be considered in the broader framework of the construction industry. It is

worth mentioning that there is limited literature on innovation in programs, so most of the sources cited in this section concentrate on the project-based approach.

2.2.1. General definition of innovation

Innovation can be defined as a new or improved product or process (or a combination thereof) that differs significantly from the units previous products or processes and that has been made available to potential (products) or brought into use by the unit (process) (OECD & Eurostat, 2018, p. 20). From this definition product and process innovation are identified (Garcia and Calantone, 2002; Russo et al., 2013; OECD and Eurostat, 2018). Product innovation is a new or improved good or service and process innovation is a new or improved business process that differs significantly from the companys previous goods/services/business processes and that has been introduced on the market (OECD & Eurostat, 2018, p. 20). In relation to a companys activity, innovation is developed usually by companies together with their suppliers (Edquist and Zabala-Iturriagagoitia, 2012) and aims to enhance productivity and effectiveness and bring long-term benefit to an organization as it is revealed in both tactical and operational projects (Sexton and Barrett, 2003; Russo et al., 2013).

Literature highlights that innovation is not just developing an invention, but also bringing it to the market and getting users to adopt it before finally being diffused in the market (Garcia and Calantone, 2002; Sexton and Barrett, 2003). Current innovation in the market that reaches technical limit will be replaced by new one. Product development, manufacturing, marketing, distribution, servicing, adaptation, and upgrade are included in the innovation process to be able to generate economic value. In addition, this process is iterative, which indicates a continuity from the first introduction to the reintroduction of improved innovation. As a result of an iterative process, two levels of innovativeness can be distinguished: a highly innovative product represents a high degree of newness, and a low innovative product has a low degree of newness (Garcia & Calantone, 2002). The probability of unforeseeable uncertainty in innovation increases with the degree of newness, as the level of uncertainty surrounding the outcomes of innovation also rises which will further induce high complexity and high uncertainty (Russo et al., 2013). However, the newness is rather problematic since its value depends on whose perspective this degree is seen and what is new; at macro level factors (such as to the world, market structure, and industry) and at micro level factors (including companies and customer) (Garcia & Calantone, 2002). Dulaimi et al. (2005) and Sexton and Barrett (2003) add that to be considered innovation, it does not necessarily have to be new to the world, but rather to the specific organizational context.

2.2.2. Innovation categorization

Product innovation in civil engineering can be described as an innovative solution, which leads to a substantial improvement in the functionality, the extension of the functionality, and/or the improvement of the technical performance of an infrastructure object (Lenderink et al., 2022). Process innovation is an innovative solution to increase the efficiency of the construction process (Lenderink et al., 2022). Other than product and process innovation, innovation can be also distinguished based on innovativeness, ranging from radical, new innovation, to incremental innovation (Slaughter, 1998; Garcia and Calantone, 2002). Radical innovation refers to a major transformation in technology that leads to a fundamental shift in the character and the nature of the industry. On the other hand, small change innovation represents an incremental innovation, and substantial innovation, falls between radical and incremental innovation.

It pertains to a product that is not necessarily ground-breaking in the market but is new to the company. At the macro level, this type of innovation may cause technology or marketing discontinuities, while at the micro level, it causes both. When a new product is created through the adaptation, refinement, or enhancement of existing products based on the current knowledge and experience, it is considered an incremental innovation, and it is only affecting the micro level, as opposed to the previous categories (Slaughter, 1998; Garcia and Calantone, 2002). It is also the reason that incremental innovation is related to low uncertainty and the majority of the innovation belongs to this group (Rogers, 2010; Gambatese and Hallowell, 2011). Opposite to incremental, radical innovation is rarely found (Slaughter, 1998; Hobday, 2000; Pries and Dore, 2005).

The development of innovation based on innovativeness (radical, moderate, and incremental) can be further related to the Technology Readiness Level (TRL) to represent a maturity level of technology. Originating from Sadin et al. (1989), TRL is scaled from basic (level 1) to commercialization. The categorization based on the degree of innovations and TRL level are used interchangeably in the literature and in this research, to identify the type of innovation that occurs within the programme. As depicted in Table 2.4, these two categorizations are utilized to distinguish between various levels of innovation.

Table 2.4: Categorization of innovation based on a correlation between the degree of innovations and TRL level based on Sadin et al. (1989) and Slaughter (1998)

Degree of innovation (Slaughter, 1998)	**TRL level (Sadin et al., 1989)**
Incremental	TRL 7 to TRL 9
Substantial	TRL 4 to TRL 7
Radical	TRL 1 to TRL 3

2.3. Innovation in infrastructure

Now that general innovation theory has been explored, this section discusses innovation in the infrastructure context. This includes the actors' interaction and their roles in innovation, innovation process in infrastructure, innovation at the sector level, and innovation in companies level.

2.3.1. Actor interaction

The construction industry can be described as a Complex Product System (CoPS) where the elements are interconnected, customized, and organized in a hierarchical way (Winch, 1998). Innovation occurs based on the three-layer system, as illustrated in Figure 2.4. The top layer consists of innovation superstructure, the bottom layer is innovation infrastructure, and system integrators are the interfaces (Winch, 1998; Rutten et al., 2009). In the top-down approach, innovation can be driven based on the demand and needs of the (public) clients while the bottom-up approach occurs through contractors and specialists learning from problem-solving on projects and adopting innovation from R&D and external sources. Innovation results from R&D can come from a collectively sectoral or national level and the innovation majority occurs as a result of collaboration between companies (Pries & Dore, 2005). The bottom layer is crucial, as two-thirds of innovation in the Dutch construction sector comes from suppliers (Pries & Dore, 2005). The literature points out that a top-down innovation approach is slower and more difficult than adopting a bottom-up approach, especially in a project-based setting (Lundberg et al., 2019).

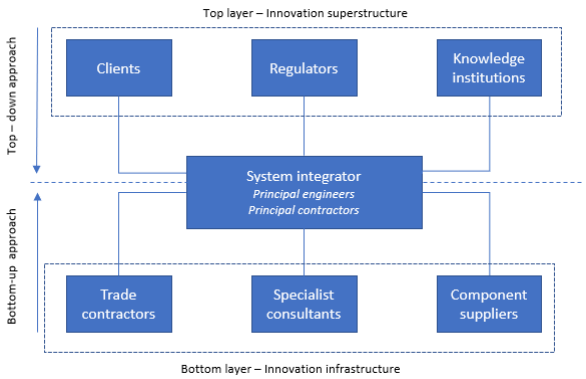

Figure 2.4: Modified Winch (1998) model (own figure)

Although the Winch (1998) framework of innovation is relatively old, the applicability of this framework is still valid to describe the interaction of various actors in the construction industry. Because of

that, this framework will be used as a foundation to explain the interaction between actors from different layers.

Role of system integrator
In the middle layer, the system integrators are typically the principal engineer and the principal contractor who play an important role in setting up and coordinating the inter-organizational innovation and own various skills and knowledge such as integrated skills, detailed knowledge of clients, rules, and regulations, responsible for the design and construction (Winch, 1998, Rutten et al., 2009). The system integrator is a common terminology whereby companies establish a strategic network of organization and oversee the process of integrating the distributed resources of the members of the network (Rutten et al., 2009; Xue et al., 2014). The system integrators in the construction industry appear to be unique due to their relatively larger size compared to the other industry (Gann & Salter, 2000). Furthermore, they are typically categorized as project-based companies due to the activities of design and production processes being organized around projects, resulting in the production of one-off or highly customized products and services. At a first analytical level, they organize and oversee a network of organizations (and supply chains) involved in the designing and building of CoPs within specified project timelines and budgets (Gann and Salter, 2000; Rutten et al., 2009). The second level focuses more on long-term cooperation. Through network set-up and network coordination, both levels are present in the innovation process and outcomes of either incremental or radical innovations are generated to meet customer needs and/or regulatory requirements (Rutten et al., 2009). To innovate in the project, the system integrator and the actors in the bottom layer interact, negotiate, and collaborate to meet the demand from the top layer. It is where the companies in the market are important sources of innovation and the system integrators create value through the integration of innovation in the design and realization of projects (Rutten et al., 2009; Lenderink et al., 2020). For a new product/process/service to be successfully implemented, it must evolve and be developed (Halman, 2018)

Role of government
The government's impact on the infrastructure sector surpasses that in other fields like IT and manufacturing due to its role not only as a public client, and a regulator but also as a financial provider (Wamelink and Heintz, 2014; Halman, 2018; Grandia and Volker, 2023). The government as a public client can stimulate innovation through R&D investment, provide innovation incentives, and facilitate technology commercialization (Lenderink et al., 2022). It can also use its purchasing power to create demand for innovative solutions by using high-quality standards and innovation-focused criteria (Lenderink et al., 2020; Lenderink et al., 2022). Furthermore, the public client's role in stimulating the diffusion of innovations is applying pressure on the supply chain partners to improve the overall projects performance and by helping them to cope with uncertainty related to it (Wamelink and Heintz, 2014; Grandia and Volker, 2023). Lack of this demand and lack of innovation knowledge hinder the effectiveness of innovation adoption in the sector (Saad et al., 2023). Literature indicates that the private sector is often less entrepreneurial therefore stimulation from the government is needed (Mazzucato, 2011; Lundberg et al., 2019). Mazzucato (2011) argues that when the government commits to support innovation by allocating budget and sharing the risk of innovation projects, radical innovation will occur from the market. As a regulator, the government can stimulate innovation by creating an environment that encourages experimentation and risk-taking while protecting public safety and interests. The availability of policy and regulation such as innovation-encouraging procurement highly influence the innovation and competition from the market by not only providing the medium to innovate but also access to funding and collaboration with actors described by Winch (1998) (Lenderink et al., 2022; EIB, 2022).

2.3.2. Innovation process

Although Winch (1998) framework centers around the traditional actors' interactions, it is essential to contemplate a comprehensive perspective of the uniqueness of the innovation process within the construction sector. Construction companies tend to prioritize the adoption of new technologies and ideas to enhance their operations, rather than investing heavily in R&D (Ozorhon & Oral, 2017). In addition, innovations in infrastructure are adopted and implemented at the project level where the actors, illustrated in Figure 2.4, collaborate (Winch, 1998). This section discusses the innovation process in construction which includes elements such as pre-conditions, drivers, inputs, outputs, and outcomes of

innovation that are unique to the sector based on the literature.

Innovations preconditions
Innovation process in construction is contributed by preceding conditions, factors, or circumstances that have an influence on the process. This is further known as pre-conditions, which based on the Cambridge Dictionary is defined as something that must happen or be true before it is possible for something else to happen. Xue et al. (2014) identifies two high-level categories of preconditions to innovations: collaboration between actors and the presence of culture. The collaboration category consists of (1) inter-organizational cooperation, (2) academia-industry cooperation, and (3) complex product systems. These collaboration factors emphasized the importance of various elements in the Winch (1998) model of innovation which consists of actors that interact with each other and collectively produce a CoPS (Xue et al., 2014). However, the diverse range of knowledge, materials, technologies, and skills across different actors' organizations creates a challenge to achieving efficient internal cooperation. In combination with poor inter-organizational cooperation, innovation especially in multi-projects is hindered (Dulaimi et al., 2002; Xue et al., 2014; Vosman et al., 2023). Literature indicates that the successful implementation of innovation will depend on high intra-organization motivation and good inter-organizational interaction (Dulaimi et al., 2005; Martinsuo and Hoverfallt, 2018). These factors are needed to ensure the integration of the supply chain, and cooperation among stakeholders beyond project-based. In relation to collaboration, Vosman et al. (2023) extends Winch (1998) model of multi-actor collaboration to include cross-industry actors such as technology suppliers and knowledge/product providers from other sectors, where between them, there is a strategic alignment with respects to a value proposition. When these actors collaborate, innovations across projects and industries are potentially created and have a greater chance to create value and contribute to cross-project or multi-project settings in the infrastructure sector (Vosman et al., 2023).

The second category is culture. Innovation is successfully diffused when a suitable climate is present. The climate in this context includes the organization's background culture, leadership, and also the influence of the team (Hartmann, 2006; Xue et al., 2014). In addition, the presence of champions (e.g. project managers) and leaders in the organization contributes to the innovation process. As an example, the commitment of project managers to the innovation process influences the culture of innovation in the organization (Xue et al., 2014). The presence of key functions in the organization is necessary not only at the company level but also at the clients' level. Clients' leadership and commitment to innovations will encourage more integration between project participants (Dulaimi et al., 2002; Xue et al., 2014). The innovation climate and the presence of champions and leaders form a precondition for cultural aspects.

Innovation drivers
Drivers can be defined as the main motivation to initiate the innovation process. The drivers to innovation can be rooted in project-related factors, companies-related factors, and sector-related factors (Xue et al., 2014). Demand for high-quality infrastructure projects from public clients is an example of drivers arising from project-related (Xue et al., 2014). Innovation can also arise due to the identified need to improve the productivity of projects' performance, increasing project complexity, and the way the project is organized (Jansen and van der Vlist, 2011; Xue et al., 2014). Closely related to project-related drivers, companies innovate based on the need to improve company performance such as to gain competitive advantage and increase profitability (Slaughter, 1998; Gann and Salter, 2000; Xue et al., 2014). However, companies' culture, policy, and leadership are indicated as drivers to innovate (Ozorhon and Oral, 2017; Bossink, 2004). In addition, companies innovate because of the need to gain knowledge networks and increase corporate image (Ozorhon and Oral, 2017; Bossink, 2004; Gann and Salter, 2000; EIB, 2022). At the sectoral-related, motivations such as following design trends, the availability of rewards schemes from public clients, and the presence of innovation-related policies and regulations stimulate companies to innovate (Ozorhon and Oral, 2017; Bossink, 2004). All these mentioned factors collectively influence the innovation process. Similarly to projects, innovations in infrastructure programme are driven by the programme's goals. As seen in the compliance type and goal-oriented programme, innovations are needed to increase the quality of infrastructure and improve the effectiveness and efficiency of the programme, such as seen in the Dutch Flood Protection Programme (DFPP) (Tromp et al., 2022). Executing the programme without innovations would be very

costly and take a considerably long time. For this reason, innovations are required to achieve the programme goal, and learning-by-doing knowledge is adopted. In addition, innovation in programme can be motivated due to the scale of the programme. As an example in Multi Water Works (MWW) programme, the replacement and renovation of 52 locks must be done by 2050 with a significant amount of investments. Standardization is therefore needed to provide more predictable operation and maintenance of the water assets. Innovations, therefore, are needed to develop a range of solutions that fit in specific context (Hertogh et al., 2018).

Innovation inputs
Innovation in construction requires key resources such as capital resources which include financial resources and human resources (Ozorhon and Oral, 2017; EIB, 2022). The financial resource is necessary for innovation to be developed such as investment for new machines and specialized equipment. Human resource is equally important to generate innovations. In the project-based industry, besides knowledge gained from education, members of an organization learn and gain knowledge from projects and this knowledge is exchanged internally through systems in the organizations. Externally, knowledge exchange occurs among the projects' team that does not necessarily come from the same organizations or parties outside the projects, such as clients, other companies, and research institutions (Xue et al., 2014; Ozorhon and Oral, 2017). In addition, the information and communication resources are considered innovation inputs because close communication and long-term cooperation and collaboration facilitate the sharing of information and knowledge between project participants. Ozorhon et al. (2010) and Rutten et al. (2009) indicate that the collaboration is not only limited to the sector but cross-sectoral collaboration also contributes to the innovation process. This also means that networks of actors are required to develop innovations.

Innovation outputs and outcomes
The investment in innovations is anticipated to yield outputs that are direct and measurable (Obwegeser & Muller, 2018). This can be in the form of intellectual property, patents, or innovative products resulting from innovation (Ozorhon and Oral, 2017; Obwegeser and Muller, 2018). Outcomes of innovations can be defined as the impact resulting from the outputs and they can be differentiated into industry level and company level (Xue et al., 2014). By using innovation, time efficiency, and resources are better utilized in projects (Gann and Salter, 2000; Dulaimi et al., 2005; Ozorhon and Oral, 2017; Noktehdan et al., 2019). The other potential outcome of innovations is the increase in productivity, efficiency, and quality of products/services that ultimately lead to an increase in client satisfaction (Dulaimi et al., 2005; Ozorhon and Oral, 2017). By responding to the pressure from clients, innovations are stimulated in projects, and as a result not only the quality of the projects are improved but the overall industry efficiency improves (Xue et al., 2014). Not only do the health and safety of the employees and people improve, but the impact on the environment is reduced during construction and after the infrastructure assets are available to the public (Xue et al., 2014; Noktehdan et al., 2019). For companies, innovations result in the improvement of images on the market that directly influence the long-term competitive benefits (Xue et al., 2014; Bossink, 2004). Taking an example from DFPP, by using innovations in the infrastructure renovation programme, the speed of renovation is increased twice, and the cost is reduced by 30% (Tromp et al., 2022). As a result of using innovations in programme, not only the quality of the renovated assets improve but also the surrounding environment (Tromp et al., 2022). Another example from the MWW programme, as an output of innovation is a range of standardized locks. The standardization results not only optimize the availability and reliability of the assets but also increase the predictability of operation and maintenance cost and time (Hertogh et al., 2018).

Framework of the innovation process in construction
The elements pre-conditions, drivers, inputs, outputs, and outcomes of innovation can be seen again in the framework of innovation in Figure 2.5. The inputs and the drivers of innovation contribute to the innovation process which generally consists of three phases: building innovation capacity (ideas phase), creating product/process innovation (conversion phase), and implementing innovation (diffusion phase) (Xue et al., 2014; Ozorhon et al., 2010). Progress made at each phase contributes to the innovation performance which can be referred to as the effectiveness and efficiency of the innovation process. Hartmann (2006) indicates that performance can be expressed as the degree to which an innovative idea resolves a problem, gains market acceptance, generates competitive advantages, and

requires resources for its implementation.

Innovation undergoes a process based on the maturity of the innovation, known as TRL. In combination with the stage of innovation from Hansen, Birkinshaw, et al. (2007), the innovation process involves the generation of ideas inside the company by acquiring inputs such as the necessary knowledge and making investments. Together with the drivers, these ideas are then converted into product, process, or process innovations. During the development process of innovations, companies (and clients) continuously encounter multiple barriers and enablers to innovation in every phase. The barriers and enablers are elaborated in Section 2.4. Finally, innovations can be further exploited in the diffusion phase to achieve benefits and impacts on its overall performance. The innovation funnel (Chesbrough, 2003), presented in a light blue triangle, illustrates the diffusion of innovation. The funnel becomes narrow as the innovation reaches validation to pass the proof of concept, before finally being ready for scale-up. The TRL level increases as the innovation is developed, scaled up by entering a new market, and eventually reaches commercialization and becomes business as usual.

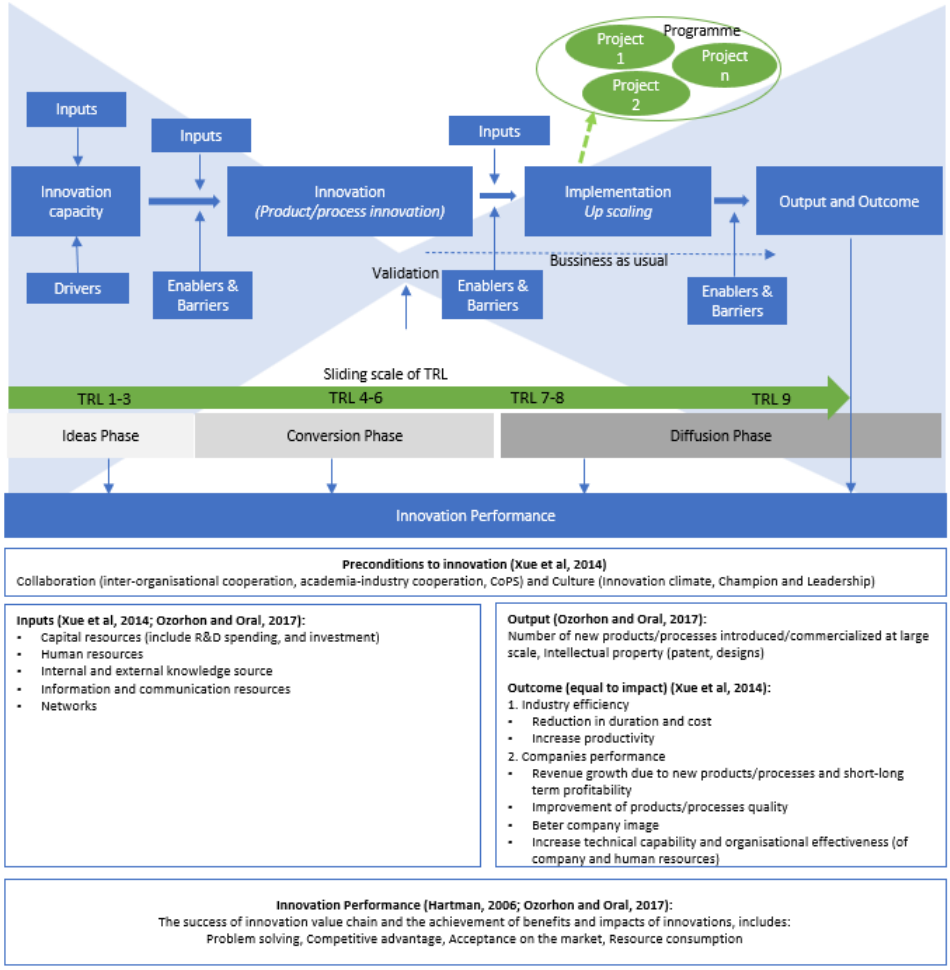

Figure 2.5: Innovation process in construction modified from Xue et al. (2014) and Ozorhon et al. (2010) (own figure)

After the validation of the technology, the innovation enters a diffusion phase, where the duration of this phase will depend on factors such as characteristics of innovations, the adopter of innovations in a social and cultural system, and time (Rogers, 2010). The adaptors of innovations in infrastructures are the public clients and the rate of adaption, representing a relation between the adopter and time, usually takes a considerable amount of time (Ortt et al., 2010). Only then, the benefits, and impacts of innovation can be seen as the output and outcome of innovations. This includes not only the improvement of the industry's productivity, reduction of duration and cost, and infrastructure product/service

quality but also the improvement of the company's performance, as well as sustainability (Edquist and Zabala-Iturriagagoitia, 2012; Xue et al., 2014). These benefits answer to the demand for innovations in the industry, companies/organizations, and projects that are often criticized due to performance dissatisfaction and inefficiency (Lundberg et al., 2019; Nguyen, 2023). Innovation especially becomes crucial when large-scale projects are predicted to increase in the future in combination with societal demand and these projects have to be delivered within the constrain of financial support and time (Edquist and Zabala-Iturriagagoitia, 2012; Adriaanse, 2014; Arnoldussen et al., 2017; EIB, 2022). Innovation is therefore needed to accelerate the pace of activities effectively and efficiently (Adriaanse, 2014; Arnoldussen et al., 2017).

Although the process depicted in Figure 2.5 mostly occurs in the project setting at project-based companies, this innovation process is highly relevant to programme context. It is because, as argued in Section 2.2, although programme undergoes a cyclical life cycle, a similar process will be seen in the infrastructure programme. Depending on the technology's maturity, an innovation proposed or implemented in the programme will undergo the same process. In the context of infrastructure, the public client is considered the first adopter of innovation. When innovation is only applied to a single project, the acceleration is hindered due to the uniqueness of a single project, or even worst, the innovation is not scaleable (Volker, 2019). While in programme, the bundling of projects will help to accelerate this adoption process. The learning during the implementation of innovation in one project can be immediately applied to inter-related projects within programme (Arnoldussen et al., 2017).

Innovation beyond projects
Despite the potential of innovation, the path to widespread implementation of innovation may be uncertain within the system in the current sector (Coenen et al., 2023; Vosman et al., 2023). Literature has pointed out that high intra-organization motivation and good inter-organizational interaction are prerequisites in the innovation process (Dulaimi et al., 2005; Martinsuo and Hoverfallt, 2018). Inter-organizational cooperation beyond individual projects is especially crucial for promoting innovation within the construction industry (Rutten et al., 2009). This suggests that a new system is required where the demand and supply interaction must be different and move from a single project approach. It is desirable that the demand should be bundled by the clients, and from the demand side, cooperation between companies or market participants is required (EIB, 2022). It is because when the demands become attractive and the supply of innovations has a promising space through collective action, implementation of innovation has a greater chance of creating value in market application (EIB, 2022).
When the demand and supply are grouped, sufficient resources (inputs) must be available from both sides, such as financial and human resources (EIB, 2022). However, the bundling of demand and supply will provide possibilities for long-term collaboration for both clients and suppliers that contribute to the achievement of the infrastructure programmes goal.

2.3.3. Innovation in the sector level

Innovation in infrastructure has been scrutinized for its lagging performance compared to other industries such as manufacturing (Volker, 2019; Lenderink et al., 2020; T. Liu and Tang, 2020; Wang et al., 2023). A typical project-based situation in the infrastructure sector creates a short-term perspective (tightly coupled project structured, competitive tendering, highly decentralized) that hinders innovation diffusion (Dubois and Gadde, 2002; Volker, 2019). In addition, the construction industry is highly fragmented due to the high demand for specialization and differentiation in the industry (Dulaimi et al., 2005; Rutten et al., 2009; Xue et al., 2014; Jones et al., 2022). This condition makes the supply chain in the construction industry stand out as one of its most notable characteristics, exhibiting a level of fragmentation that surpasses that of almost any other industry (Xue et al., 2014). The knowledge, materials, technologies, and skills are diffused among various organizations. The so-called integration in the construction process mostly focuses only on the reduction of vertical fragmentation between the construction phase of the project. In contrast, the horizontal fragmentation between suppliers and their supply chain, and longitudinal fragmentation between projects are less likely addressed (Volker, 2019; Jones et al., 2022). At horizontal fragmentation, various actors deliver products and services by specialists by approximately the same stage of a process while longitudinally, the project team is dissolved and/or reassigned by the end of a project where the accumulated knowledge is also displaced and removing the opportunity of organizational learning and continuous improvement (Jones et al., 2022).

Although the learning attempt is made through a knowledge management approach, the project uniqueness suggests that the accumulated knowledge is non-generalized (Jones et al., 2022).In addition, the economic scale becomes a challenge, as well as the difficulty to transfer knowledge (Kulatunga et al., 2006). On the other hand, due to the uniqueness of every project, a new approach is needed, and it is associated with innovative behavior (Kulatunga et al., 2006). It is where the programmatic approach arises as a new way to organize multiple projects that frequently failed due to a project-based approach (Arnoldussen et al., 2017; Volker, 2019). Although innovation is facing obstacles in implementation, innovation is urgently needed to accelerate the progress of the programme due to its positive influences on the infrastructure programme.

However, literature shows that construction companies have always shown a capability for innovation but face challenges with the implementation, therefore, they gain a minor advantage (Slaughter, 1998; Lundberg et al., 2019). Although it is debatable, the absence of innovation is not due to a lack of innovativeness capability but rather the result of an uncoordinated effort to connect market demand despite adequate demand and supply of technology (Kulatunga et al., 2006; Lundberg et al., 2019). It implies that the involved actors shall work in close and stable relations to contribute to the development and accelerate the adoption of innovations (Rutten et al., 2009). As indicated earlier in Section 2.3.1, the existence of public policy demonstrates the government's dedication to shaping the trajectory of innovation. Specifically, the presence of procurement law that supports innovation-oriented procurement is unquestionably necessary for effective innovation implementation (OECD & Eurostat, 2018). More about procurement for innovation will be explained in a later section.

2.3.4. Innovation in infrastructure companies

Innovation does not only answer the sectoral challenge but also project-specific demand (Dulaimi et al., 2005; Koopmans, 2021). Innovation in projects is well recognized due to the need for reduction of costs and acceleration of the construction process. Increasing the number of projects and high focus on safety, and demand for high productivity, are some of the motivations for companies in the infrastructure sector to innovate (Benmansour and Hogg, 2002; Dulaimi et al., 2005). Some of the other drivers of innovation have been described in Section 2.3.

Companies innovate within the innovation trajectory and it is shaped by the internal forces, stems from resource-based view and external forces, based on market-based view of innovation (Sexton & Barrett, 2003). The market-based view implies that companies use innovation to adapt and orient themselves to take advantage of changing markets where it provides initial conditions that either facilitate or constrain the direction and extent of companies innovation activity (Sexton & Barrett, 2003). In addition to market influence, technological, economic, political legal, and physical factors shape the trajectory of the infrastructure sector (Hartmann, 2006; Wamelink and Heintz, 2014; Volker, 2019). The actual need of the environment must be the driver to change direction, and this can be done by closely involving actors in the early stages until the implementation of projects or programme (Uyarra et al., 2014; Wamelink and Heintz, 2014). Such a need for innovation can be clearly seen in the large-scale renovation and replacement programme of infrastructure assets in the Netherlands (EIB, 2022; Rijkswaterstaat, 2022). To enable investment in innovation, companies require a clear perspective and understanding from public clients. An innovation-friendly environment is needed, where companies can nurture ideas and effectively implement innovative solutions that will yield positive outcomes for their business. This innovation space is essential for companies to develop and execute ideas that drive positive impacts on their overall operations (EIB, 2022).

On the other hand, the resource-based view suggests that companies attempt to balance out the internal organizational capability and the existence of external competition. The collective set of values and beliefs, demonstrated through the behaviors and actions of the organization members, influence companies' level of innovativeness (Hartmann, 2006). Through strategic management, innovative companies adopt a long-term-oriented strategy that reflects shared vision and goals, forming the basis for their business priorities (Hartmann, 2006; Jansen and van der Vlist, 2011). By incorporating innovations into projects, companies aim to achieve desired innovation performance, such as increased profitability compared to non-innovative approaches. To remain competitive and enhance market share, companies continuously pursue innovation as a means to achieve desired levels of productivity (Hartmann, 2006;

Jansen and van der Vlist, 2011).

These two forces also mean that companies use product and/or process innovations in projects to excel in their performance and manage to retain their competitiveness, provide client satisfaction, and deliver quality products/services which will increase their turnover and profitability (Jansen and van der Vlist, 2011; Ozorhon et al., 2010; Xue et al., 2014). Specifically in the Netherlands, the majority of the innovation in innovations originated from companies' supply chains and they are dominated by incremental innovation (Pries & Dore, 2005). Jansen and van der Vlist (2011) argues that companies in the construction industry improve their business performance and gain a competitive advantage due to increasing productivity and long-term innovation-oriented strategy and improvement of organizational skills.

When correlating the infrastructure at the industry and company level, two points are emphasized. One, the acceleration of innovation at the sector level is crucial and innovation at the companies' level plays a role in the overall industry even though the focus is more on competitiveness (Wamelink & Heintz, 2014). Second, alignment of strategic goals of suppliers and public clients is urgently needed to accelerate the progress of infrastructure projects through innovation (Barlow, 2000). This also means that multiple implementations of innovation on inter-related projects are preferred to achieve long-term goals that will benefit not only the companies but also the public clients (Arnoldussen et al., 2017). A shift towards a long-term collaboration and attractive incentives are therefore needed to engage suppliers (Xue et al., 2014; Volker, 2019) and this can be done by moving away from a single project approach to a programmatic approach (Arnoldussen et al., 2017; Volker, 2019).

2.4. Barriers and enablers to innovation in infrastructure

Framework of innovation as depicted in Figure 2.5 shows a number of elements that contribute to the innovation process. It can be seen that barriers and enablers to innovation can be found in various innovation phases. Identification of barriers and enablers will help to develop strategic planning for implementing innovation in programme. In this section, focus will be given to barriers and enablers of innovation. Barriers in this research refer to the factors that disrupt the development and implementation of innovation and enablers are the factors that act as vehicles to mobilize the innovation efforts and mitigate the negative impacts of the barriers (Ozorhon & Oral, 2017). Some enablers are designed to target specific barriers, while others are a way to improve conditions, and potentially solve multiple barriers (Hart et al., 2019).

2.4.1. Barriers to innovation

Evidence indicates that efforts have been made to develop and implement innovation in infrastructure projects. However, the process of developing and implementing innovation is often obstructed by various barriers that impede the progress of these projects. The literature discussing these barriers has identified them but does not clearly distinguish them according to the phase of innovation as seen in Figure 2.5. Furthermore, the majority of barriers identified in the literature are inherent to the project-based approach, and these barriers have the potential to impact both the organizational level of companies and the industry as a whole. Additionally, it is worth noting that only a limited number of literature sources discuss the contextual aspects of programme such as Vosman (2020), and the barriers related to project context are relatable to multi-project settings such as programme.

In this research, the barriers are categorized into contract and regulation, financial, collaboration & cultural-related, technological, knowledge exchange, client-related barriers, and market-related. The description of these barriers is presented below and they are summarized in Table 2.5. Codes are assigned to these barriers based on their categories.

Contract and regulation barriers

Regulation barriers are the factors related to the policy and regulation. It means that the procurement process is also included in this category. Restrictions on the tender elements such as requirements and specifications are repeatedly mentioned in the literature as a factor hindering innovation (Uyarra et al., 2014; Arnoldussen et al., 2017; Hart et al., 2019, Vosman, 2020, Koopmans, 2021). In addition, the

lack of incentive seen by the companies as a demotivating factor to use innovation, which is usually associated with high investment (Benmansour and Hogg, 2002; Gambatese and Hallowell, 2011; Uyarra et al., 2014; Oesterreich and Teuteberg, 2016; Hart et al., 2019; Vosman et al., 2023). Incentive, in this case, is not only financial related but could be knowledge and network related. Restriction on the requirement and lack of incentives are frequently seen in the current procurement practice and it is pointed out as factors that do not promote a long-term buyer relationship (Uyarra et al., 2014; Martinsuo and Hoverfallt, 2018). In addition, literature has shown that the policy and regulation are rigid and do not allow flexibility or creativity which are needed to foster innovation (Benmansour and Hogg, 2002; Arnoldussen et al., 2017; Koopmans, 2021; Coenen et al., 2023; Vosman et al., 2023). At the same time, research from Benmansour and Hogg (2002) and Arnoldussen et al. (2017) has shown that government policies are also lacking consistency and rigor. The rigidity of regulation has also negatively influenced the low-level formality outside formal procedure (Arnoldussen et al., 2017; Vosman, 2020).

Financial barriers
In this category, factors that hinder the companies to gain monetary benefits are considered. The innovation process is seen as a high upfront investment process that required a long-term payback period before finally monetary benefit can be gained (Adriaanse, 2014, Arnoldussen et al., 2017,Gambatese and Hallowell, 2011, Uyarra et al., 2014, Benmansour and Hogg, 2002; Oesterreich and Teuteberg, 2016; Hart et al., 2019). This is associated with the lack of short-term profitability for the companies. In addition, the long duration of the development of innovation demotivates the clients and the companies which results in insufficient volumes of work that use innovation. This results in a lack of scaling possibility of innovation. Innovation is associated with uncertainty and risk, therefore the adverse behavior of the clients and the companies towards the risk influence the monetary factor (Arnoldussen et al., 2017; Nguyen, 2023). Furthermore, as written by Hart et al. (2019), the poor articulation of the business case and insufficient, incomplete, and poorly communicated case study hinder the development and implementation of innovation.

Collaboration and cultural barriers
Cultural barriers in this research refer to social aspects, behavioral, and managerial aspects. Norms, interests, incentives towards innovators, and organization structure such as hierarchy, communication, flexibility, freedom, and openness are pointed as organizational factors that hinder innovation (Hart et al. (2019), Benmansour and Hogg (2002)). In general, the construction industry is associated with a strong and rigid culture along with a notable reluctance to embrace changes (Oesterreich & Teuteberg, 2016). These factors are closely related to the way the organization collaborates both in the context of vertical and horizontal collaboration, between client and market participants (Hart et al., 2019). Lack of stakeholders acceptance of innovation is also pointed as a contributing factor hindering the further development and implementation of innovation (Koopmans, 2021). Stakeholders in this context include all the parties influenced by the projects and they can be from internal or external clients and/or companies. In addition, as Winch (1998) model of innovation suggests, companies do not innovate in isolation but rather collaborate with their networks to produce innovation. The absence of network and inter-organizational collaborative effort, therefore, hinder the innovation process (Martinsuo and Hoverfallt, 2018; Trzeciak et al., 2022).

Technical barriers
Within the actors' network, technical capability and staff competencies are crucial factors to develop innovation (Gambatese and Hallowell, 2011; Koopmans, 2021). Gambatese and Hallowell (2011) and Nguyen (2023) argue that the technical capacity and competency of project teams is one of the prerequisites of successful innovations implementation. Technical challenges are another factor that hinders the development of innovation. A lack of understanding of certain techniques and technologies is indicated as a barrier (Hart et al., 2019).

Knowledge exchange-related barriers
Knowledge exchange-related barriers encompass obstacles that impede the transfer of knowledge within and between organizations. This barrier is closely related to technical and collaboration-related barriers because these factors influence the development and implementation of innovation (T. Liu & Tang, 2020). This category is created to organize the factor that hinders the exchange of knowledge in the

internal and external organizations relative to the organizations, therefore it is separated from the collaboration-related category. As an example, effective communication in internal projects and organizations can assist knowledge transfer thus fostering innovations (Nguyen, 2023). Moreover, the lack of engagement with external parties poses a barrier to bridging the knowledge gap (Uyarra et al., 2014; Bossink, 2004). This issue is particularly relevant in the infrastructure industry, where innovation is often derived from external sources rather than developed internally. The adoption of technology in this sector necessitates the transfer of knowledge and technology (Ozorhon & Oral, 2017). Knowledge transfer takes place within a network of interdependent suppliers, customers, and regulators(Gann and Salter, 2000; Ozorhon and Oral, 2017). However, the transfer of knowledge and innovation in infrastructure projects is typically hindered by the market condition predominantly influenced by procurement practice (Lundberg et al., 2019). Additionally, the absence of a knowledge management system or a mechanism for capturing lessons learned falls under this category of barriers (Bossink, 2004; Barlow, 2000).

Client-related barriers
This barrier category encompasses various aspects associated with the clients. One significant issue is the lack of a long-term view and standardization in the management approach of public clients who act as asset owners (Vosman et al., 2023). This deficiency can be attributed to the project-based approach to budget management by the public sector, as highlighted by Halman (2018) and EIB (2022). The project-based situation influences the continuity of innovation. Furthermore, these factors are interconnected with the previously mentioned Financial-related barriers. Furthermore, Uyarra et al. (2014), Gambatese and Hallowell (2011). Nguyen (2023) and Saad et al. (2023) argue that clients' limited understanding of innovation and procurement for innovation significantly influences both the procurement outcomes and the demand for innovation. Lacking demand for innovations includes the scarcity of a large-scale demonstration project (Bossink, 2004) as well as a lack of bundling of projects. Uyarra et al. (2014) mentions that to develop innovation, the interests of the clients and their active involvement is required from an early stage of projects.

Market-related barriers
Literature indicates that the market has an influence on the development of innovations. As indicated by Nguyen (2023) and Gambatese and Hallowell (2011), economic turbulence hinders innovation, such as the COVID-19 crisis that influenced the price and availability of construction materials. In addition, the competition level in the market could become a barrier to innovation, especially at market-driven prices (Ozorhon and Oral, 2017; Oesterreich and Teuteberg, 2016). The competitive environment results in a tight profit margin and furthermore could be the reason for a limited R&D budget of construction companies (Oesterreich & Teuteberg, 2016). Furthermore, the traditional perspective of the market to innovation plays a role in the development of innovation, where only proven technologies are preferred (Nguyen, 2023; Oesterreich and Teuteberg, 2016). Market-related barriers can be further correlated to client-related barriers which are rooted in the project-based approach (Vosman, 2020).

Literature has shown that development and implementation of innovations in projects is the major challenge (Xue et al., 2014) and programme become necessary to overcome this challenge such as argued by Arnoldussen et al. (2017), and Vosman et al. (2023). The barriers to innovation mostly originated from the project-based approach and can be rooted down due to scale-up issues. Companies recognize that innovation involves risk and may not yield immediate returns. To effectively incorporate innovation, suitable strategies must be defined. Companies that regularly engage in similar projects may find it more practical, as they can apply the same innovations to future undertakings (Ozorhon & Oral, 2017). Similar projects in the companies' perspective may not be necessarily in the same programme, however, it can be temporarily concluded that a multi-projects setting will be more desirable for the implementation of innovation. Other literature has also shown that programme become necessary to overcome the scaling issue (Arnoldussen et al., 2017; Koopmans, 2021; Gomez Chica, 2022; Vosman et al., 2023). In the next section, enablers to innovations are presented and potentially become solutions to these barriers.

2.4.2. Enablers to innovation

Enablers are further identified in the literature, as seen in Table 2.5. The enablers are categorized similarly to the barriers: contract and regulation-related enablers, financial enablers, collaboration and cultural-related enablers, technical-related enablers, knowledge exchange enablers, and client-related enablers. Each of these enablers is linked to the barriers (code) that are identified in the previous section. These enablers can be related to the same category of barriers, but also become enablers for multiple barriers from various categories. It can be noticed as well that the market category does not appear as the enabler anymore, because the market-related barriers can be solved with enablers from other categories. The summary of enablers in correlation with barriers can be seen in Table 2.5

Contract and Regulation-related enablers

Based on the identified barriers related to contract and regulation, there is a need to have strong policy support to promote long-term collaboration and stimulate innovation (Hart et al., 2019; Lenderink et al., 2022; Vosman et al., 2023). Dutch procurement law is highly influenced by EU procurement law. The presence of policy and targeted policy for innovation can promote the various collaboration form that stimulates and support innovation, such as the use of framework agreements, innovation partnerships, or two-phase contracts (Lenderink et al., 2022; Vosman et al., 2023). Through a suitable incentive scheme, these types of collaborations are able to influence and overcome the financial-related barrier to monetary benefits, such as the high cost and long payback period of innovations. Literature also indicated that the infrastructure industry shall move away from strict requirements in the tendering, but instead focus on the functional specification because it will stimulate creativity from market participants and create space for innovative solutions (Edquist and Zabala-Iturriagagoitia, 2012; Volker, 2019; Lenderink et al., 2022). However, policy and regulation, as noticed in the barrier section, are two folds. The policy and regulation can act as enablers of innovation but also as barriers depending on how it is used.

Financial-related enablers

A sufficient demand for innovation is seen as an enabler of innovation (Lenderink et al., 2022; Edquist and Zabala-Iturriagagoitia, 2012; Hart et al., 2019). It implies that with sufficient demands, it provides a volume that is needed by innovation to scale up. To provide these demands, it is suggested that public clients should consider more of a whole life cycle approach on its assets (Hart et al., 2019). In a solid business case, the high investment in innovations is spread out over a longer period of time with a more acceptable risk (Hart et al., 2019). In addition, with sufficient time, the innovations can further enter a diffusion phase that will eventually help the commercialization of innovations. As noticed, these financial enablers are closely related to the regulatory enablers that are mentioned earlier. As indicated by Gann and Salter (2000), Ozorhon et al. (2010) and Vosman et al. (2023), the presence of incentive schemes will help to foster innovation. In addition, the presence of an innovation-related policy helps regulate a grant and provide attractive funds for innovation that will not only solve the financial-related barriers to developing innovation but also support demonstration projects that are needed for innovations to be developed (Hart et al., 2019).

Collaboration and Cultural-related enablers

Literature has indicated that leadership from key personnel, such as project managers, can highly influence innovations in projects (Ozorhon et al., 2010; Dulaimi et al., 2005; Hart et al., 2019). Closely attached to the organization's culture, leadership is needed not only from clients but also from companies. Dulaimi et al. (2005) and Gambatese and Hallowell (2011) argue that there is a strong correlation between owner interest and investment in innovation to facilitate the development of innovative solutions that benefit the projects. In addition, understanding customers and stakeholders is another enabler found in the literature. Ozorhon et al. (2010) argues that the collective actions and opinions of customers and stakeholders can help drive innovation in the projects. Limited budget, current asset management practice, and clients' capabilities are some of the clients' challenges. Engaging the customers and stakeholders at the earlier stage of projects or programme will help to overcome these barriers because only by understanding their needs and challenges, potential innovative solutions can be proposed and developed (Ozorhon et al., 2010, Uyarra et al., 2014, Koopmans, 2021). Therefore, innovations would be potentially accepted. This is also aligned with the Winch (1998) model where innovation is co-developed with customers and supply chain at project-level (Ozorhon et al., 2010). In

addition, one of the ways to facilitate this process is through maintaining a long-term relationship between clients-companies (Hart et al., 2019). Closely related to the understanding of the customers and stakeholders is the creation of a system and culture that support innovation. As indicated by Ozorhon et al. (2010) and Dulaimi et al. (2005), providing the supporting environment in the organization such as training, promoting knowledge sharing, and the organization's vision influence the innovation process. A stimulating environment presence inside the organization and the industry (such as network) can be a potential solution to some of the collaboration-related barriers essentially required in the innovation process (Ozorhon et al., 2010; Bossink, 2004; Martinsuo and Hoverfallt, 2018; Vosman et al., 2023). Literature also indicates that the presence of trust, co-alignment, and co-opetion are pre-requisites for the successful development and implementation of innovation in projects (Bossink, 2004; Hart et al., 2019; Vosman et al., 2023). In addition, low-level formalities, beyond contractual, will provide a supporting innovation environment because it gives the actors in the networks more flexibility to produce an innovative solution beyond their capability (Vosman et al., 2023).

Technical-related enablers
Although innovation is a network co-creation process, the technical capability of companies is still crucial for companies to develop innovation (Bossink, 2004). Furthermore, the availability of R/D is important to support technological capability. Through a network of actors in projects, knowledge is exchanged and solutions to problems are developed (Ozorhon et al., 2010; Bossink, 2004).

Knowledge sharing-related enablers
As described in the section 2.3, the interaction between a network of actors plays a crucial role in innovation (Winch, 1998). The actors in the network mobilize knowledge (Gann and Salter, 2000; Bossink, 2004; Vosman et al., 2023). As an example, research institutions and consultants played a crucial role in transferring scientific knowledge to practical applications. Effective knowledge sharing is essential to diffuse ideas into projects and ensure they are known by the involved people in the projects(Ozorhon et al., 2010). The knowledge that is diffused in people through projects will contribute to the knowledge on the market. Vosman et al. (2023) argues, that diverse knowledge in the market is beneficial to look for innovative solutions. In addition, knowledge centers also can act as an enabler that promotes the exchange of knowledge among commercial organizations in the industry (Bossink, 2004). While the presence of the R&D department is rare in infrastructure companies, innovative client and market participants embraced an informal research and development (RD) function, integrating it into their projects to exchange valuable information and knowledge (Bossink, 2004). In addition, the presence of formal and informal training in the organization facilitates knowledge exchange (Bossink, 2004).

Client-related enablers
Closely related to leadership, the literature indicates that a clear vision and commitment from the client acts as an enabler to innovations (Ozorhon and Oral, 2017; Vosman, 2020). This means that the policies that support innovation and the long-term vision need to be translated into action and (Vosman, 2020). Active involvement of clients in the innovation process is recognized as an enabler of innovations (Xue et al., 2014; Dulaimi et al., 2005; Kulatunga et al., 2006). This includes the willingness of the public client to facilitate pilot projects and bundling projects (Bossink, 2004; EIB, 2022). Furthermore, this factor is closely related to the clients' skills and behavior such as value judgment, competence, motivations, and flexibility (Kulatunga et al., 2006).

Table 2.5: Enablers to innovation in correlation with barriers (Own table)

Barriers	Code	Enablers	Link
Contract and Regulation-related		**Contract and Regulation-related**	
Lack of long-term buyer-supplier relationship, related to collaboration form	CR1	Policy support that promotes a long-term collaboration	CR1, CR2, CR4, CR5, F1,
Restriction on tender elements (requirement and specification too rigid, and lacking financial incentive to innovation)	CR2	Using suitable collaboration forms for innovation (framework agreement, innovation partnerships, two-phase contract)	CR1, F3, F4, F5
Lack of explicit information about the need for innovation	CR3	Policy support to stimulate innovation (such as promoting using functional specification instead of technical)	CR2, CR3, S3, S7

Lack of systematic and consistency on government policy	CR4	Flexibility on tender requirement (more functional specification)	CR1
Rigidity enforcement of policy and regulation	CR5		
Lack of reputation mechanism outside the formal procedure	CR6		
Financial-related		**Financial-related**	
Difficulty to internalize the benefits (high cost, long payback period, lack of profitability)	F1	Sufficient demand for innovation (related to volume and scalability)	F1, F2, F3, F4, F5, S5, S7
Financial resource availability (related to high investment)	F2	Presence of incentive schemes	F1, F2, CR1, S7
Risk adverse behaviour of client (and suppliers)	F3	Grants and funds for innovation (such as SBIR)	F1, F2, S7
Risk in commercialising innovations	F4		
Uncertainty of application which results in lack of continuity, limited scaling	F5		
Collaboration and Cultural-related		**Collaboration and Cultural-related**	
Absence of collaborative effort with networks of actors (with/without client)	C1	Leadership (including clients and companies)	S1, S4
Organization culture (norms, attitude towards risks, incentive towards innovator) and structure (hierarchy, communication, flexibility, freedom, openness)	C2	Understanding of the customer and stakeholders	S1, S2, S3, T1, CT1
Lack of stakeholders acceptance of innovation	CT1	System (e.g network configuration) and culture supporting innovation (e.g education, training, vision, supporting environment, understanding innovation context)	C2, S2, S3, S4, CR2
		Presence of trust (in the form of goal alignment)	S4, S6
		Presence of low level of formalities	S6
Technical-related		**Technical-related**	
Lack of technical capability (technology, R&D, and staff)	T1	Technical capability	T1
		Availability of R&D	T1
		Available network to support collaboration and knowledge exchange	CR6, C1, C2, T1
Knowledge sharing-related		**Knowledge sharing-related**	
Lack of internal knowledge sharing mechanism (training, knowledge sharing sessions)	K1	Presence of knowledge management practice and problem-solving technique internal to companies	T1, S3
Lack of external knowledge sharing mechanism (minimum interaction with external parties, lack of network configuration)	K2	Presence of knowledge sharing mechanism with an external party (e.g knowledge institute, knowledge center)	T1, K2
		network configuration	T1, K2
Client related-related		**Client related-related**	
Management asset by public domain (lack of standardization)	CL1	Clear vision from client	CL1, CL2, CL4, M1, M3
Limited budget allocation of public commissioning	CL2	Promote coopetition and cooperation (between contractors/suppliers)	M1, M3
Lack of clients procurement capabilities	CL3	Dynamic involvement of client	CL4
Lack of clients involvement	CL4		
Lack of demand and unclear demand to innovation from public clients	CL5		
Lack of inter-organisational collaboration	CL6		
Lack of large-scale demonstration projects to prove technology	CL7		
Market		-	
Traditional perspective of the market to innovation	M1		
Market influence (price, demand, crisis)	M2		
Competition level	M3		

2.5. Public procurement for innovation in the Netherlands

This section describes briefly the method of procurement for innovation in the Netherlands and the current mechanism on how procurement of programme is arranged.

2.5.1. Public procurement

As an EU member, Dutch procurement law is shaped by EU Directive 2014/23/EU. This law governs government procurement of works, supplies, and services, including tendering processes (EuropeanUnion, 2014). Entities like Rijkswaterstaat, municipalities, and provinces are obliged to adhere to this law, which encompasses different tender procedures (open, restricted, limited). The choice of procurement model has a substantial impact on the civil engineering sector, influencing project organization and procurement for innovations. The delivery procedure in the public sector generally consists of three phases: preparing, purchasing, and performing. Each phase consists of steps that lead to a continuous and circular process (Grandia & Volker, 2023).

The preparation phase involves exploration by the public client, followed by the initiation step where objectives, scope, budget, and procurement strategy are defined, similar to project initiation (Uyarra et al., 2014). The expected benefits of the programme become evident during its early phase, and consequently, the benefits of innovation can also be identified in the initial stages of the programme (Wamelink and Heintz, 2014; EIB, 2022). Depending on the client's capabilities, a market consultation is conducted to seek input from market parties regarding the program's development. Involving market participants early on in the process enhances the likelihood of successful development and implementation. This early involvement allows companies to gain a clear understanding and perspective from public clients, facilitating the nurturing of ideas and investment in innovation (Uyarra et al., 2014; Wamelink and Heintz, 2014; EIB, 2022). In the purchasing phase, the tendering method is chosen. In this step, the selection and award criteria are determined before moving to the other procurement process such negotiation and award process (Lenderink et al., 2022; Grandia and Volker, 2023). Projects/programmes are executed after the contract is awarded.

In relation to simulating innovation, EU procurement provides several methods to open opportunities for innovation in the market such as competitive dialogue, market consultation, pre-commercialize procurement, and innovation partnerships (EuropeanUnion, 2014; Uyarra et al., 2014). The details of these procurement methods are beyond the context of this research but a brief explanation is provided in the next section. Instead, this research looks at various innovation-encouraging procurement as part of the observation. It is worth to understand that there is a downside to this procurement law. The EU procurement law implies that demand-oriented procurement is preferred over offer-oriented approaches (Halman, 2018).

2.5.2. Procurement for innovation in Programme

While a project is purchased using a so-called project delivery method, the method for delivering a programme does not yet exist. An attempt has been made for creating programme delivery method such as a model created by Lutt (2021), but its applicability remains at the theoretical level. However, procurement for innovation in projects/programme in civil engineering has been done in several ways. There is a growing perspective that public clients hold the capacity to stimulate innovation because, in the procurement process, a supportive environment for innovation is created (EuropeanUnion, 2014; Obwegeser and Muller, 2018; Lenderink et al., 2022). As an example, public clients help limit the financial risk or provide attractive incentives to the contracted parties. In the procurement for innovation, not only the outcome of innovation is purchased but also the development of innovation is facilitated during the procurement process (Uyarra et al., 2014; EuropeanUnion, 2014; Koopmans, 2021). It means that a long-term relationship between public clients and market parties are encouraged (EuropeanUnion, 2014). Research from Lenderink et al. (2022) indicates various innovation-encouraging procurement strategies as seen in Table 2.6 below. The framework incorporates various elements of categorization that are important to identify the rationale for how the innovation in programme/projects is purchased. Depending on the type of innovations (as discussed in Table 2.4), a specific tendering procedure is chosen, either using competitive dialogue, innovation partnership, or Small Business Innovation Research (SBIR) (EUComission, 2018). The brief explanation is provided as follows:

- Competitive dialogue is a two-round process initiated by public clients in which their requirements are outlined in a descriptive document or contract notice. The minimum requirements for candidates and the contract award criteria, based on the Best Price Quality Ratio, are also defined in this procedure. Once the candidates are selected through the verification process, the negotiation is taken place individually with each candidate to ensure the confidentiality of each solution.

The competitive dialogue potentially results in a wide range of innovative solutions (EUComission, 2018). Compared to traditional tender procedures, the adoption of competitive dialogue facilitates greater negotiation and communication concerning the scope and as a result, the tenderer can optimize their business case with respect to the development and implementation of innovation (Lenderink et al., 2022, p. 24).

- Innovation Partnership is a relatively new addition in EU Procurement, added in 2016 (EUComission, 2018). For procuring products, services, and works that are not yet available on the market, an innovation partnership procedure is used by the public client. The innovation partnership procedure includes three phases. The selection phase starts the procedure of innovation partnership where suitable partners are selected after a call for competition and the contracts are awarded to these selected partners. In the second phase, the products, services, or works are developed in R&D phase until becoming a commercialized output. This phase consists of several stages ranging from concept evaluation, development of prototypes, and testing before finally becoming a commercialized output. In the third phase or commercialize phase, the public client purchases the outputs in a volume under the agreed condition in the partnership agreement (EUComission, 2018; Pianoo, 2023a).
- SBIR is a pre-commercialized procurement approach to trigger innovation where the public clients procure research and development services at advantageous conditions from market parties instead of reserving the benefit exclusively (EUComission, 2018). This approach is indicated as a mutually beneficial solution because the intellectual property results from the contract remain with market parties and the public clients can use the result based on their own needs and license the solution in a follow-up public procurement (EUComission, 2018, p. 56).

Table 2.6: Short version of innovation-encouraging procurement strategy for programme based on Lenderink et al. (2022) (Own table)

Characteristics	**Regular programme (innovation-friendly)**	**Innovation oriented programme**	**Innovation-driven programme**
Aim and objectives	Product and process improvement in multiple project	Product and process development through subsequent projects	Product and process development through subsequent projects
Scope	Continuous improvements and optimizations	Development and implementation of promising possibilities	Innovation focussed on a specific topic
TRL level (at the start of programme)	High TRL level (8-9)	Medium TRL level (6-7)	Low TRL level (3-4)
Type of realization innovation	Incremental product and/or process innovation	Substantial product and/or process innovation	Radical product and/or process innovation
Budget for innovation	Not applicable	Integrated in total programme budget	Dedicated in total programme budget
Tendering procedure	Competitive dialogue	Competitive dialogue (Best Value)	Innovation partnership, SBIR
Project delivery model	Concession, DBFM	Two staged approach (Development/Framework Agreement)	Two staged approach (Development/Framework Agreement)
Awarding criteria	Quality/price ratio	Quality achieving programme goals/price ratio and Collaboration	Quality of collaboration, Innovation competencies and achieving programme goals
Pricing	In competition	Negotiated as business case (adjustable scope)	Negotiated as business case (adjustable scope)

The project delivery model also ranges from a concession to a two-stage approach (Lenderink et al., 2022). It can be seen in the table above that the development/framework agreement through a two-staged approach is used to purchase innovation-oriented or innovation-driven programmes. A two-staged approach is recognized as a suitable approach for innovation because it separates the development and implementation (Lenderink et al., 2022). The first stage is innovation is developed under the development agreement and, once the development of desired products/services/works is successfully completed, they are purchased under the framework agreement.

A framework agreement can be defined as an agreement between contracting authorities and supplier(s) for awarding a stream of future contracts as per agreed conditions, such as price, quality, quantity, and delivery time. These conditions serve as the criteria for awarding subsequent contracts throughout the duration of the agreement (Pianoo, 2023b). Framework agreements are widely recognized as an effective procurement technique across Europe because, after the tendering of a framework agreement, the process for a bid and award process possibly becomes simpler since most of the conditions for the future contract have been agreed (EuropeanUnion, 2014). This leads to a significant reduction in total transaction costs for engagement and performance monitoring by contracting authorities and, therefore can potentially result in significant cost savings (Lam & Gale, 2014). The typical duration of a framework agreement is generally four years duration but it can be extended under special circumstances (Pianoo, 2023b). The downside of this type of agreement is, that the contracting authority is tied to specific parties within the agreement and limits the market contribution to the projects, especially in the highly fluctuating market. In addition, agreements with multiple contracted parties are not preferred by the market participants because there is no certainty of awarding the contracts, while effort still has to be made to be included in the agreement (Lam and Gale, 2014; Pianoo, 2023b). Concerning innovation, development/framework agreement facilitates the development and implementation of innovation because the public clients can use it for individual, repetitive, and large volume purchase (EuropeanUnion, 2014).

2.6. Conclusion of theoretical background

The main objective of this literature section is to acquire a broad comprehension of infrastructure programs and the innovation process within them. Drawing on this knowledge, a preliminary framework is devised for the development and implementation of innovations within such programs.

Infrastructure programme and characteristics
Based on Section 2.1.1, it can be concluded that an infrastructure programme is a unique endeavor where a collection of interrelated projects is managed in an integrated manner to achieve optimum benefits for stakeholders and organizations. The programme's overarching goals cannot be achieved if the individual projects are managed separately.

Infrastructure programmes are driven by a primary goal, influenced by the role of public clients as the owners of infrastructure assets, which is to provide safe and reliable infrastructure assets for users. Compliance with this goal is crucial, as it ensures the availability and functionality of the assets. Furthermore, the infrastructure programmes aimed at fulfilling the strategic objectives of the government by leveraging synergy and centrally coordinated projects. This makes the infrastructure programme also a vision-led programme, based on programme's categorization from OGC (2011). Opportunities to add value beyond the primary goal may arise from the ambitions of the public organization, such as sustainability and circularity initiatives. An example of added value is the improvement of existing infrastructure to serve multiple functions. The added values to a programme become secondary goals of the infrastructure programme. In addition to the primary and added value goals, infrastructure programmes may also have conditional goals that need to be fulfilled to achieve the primary goal. These conditional goals, such as innovation, directly influence the efficiency and effectiveness of the programme. Majority of infrastructure programmes are compliance-oriented, primarily driven by the need to provide safe and reliable infrastructure assets. However, they may also incorporate added value and conditional goals based on the ambitions and needs of various stakeholders involved in the programmes. Effective management and coordination of these goals are essential for successful infrastructure programme execution.
Based on the literature, infrastructure programme can be identified based on ten characteristics:

1. Inter-related multiple infrastructure projects that are centrally coordinated by programme organization and integrated to achieve organizational benefits
2. Government-initiated programme in infrastructure can be vision-led or compliance-focused, aimed at meeting safety requirements, implementing strategies, changing business operations, achieving the organizations strategy, and fostering collaboration
3. Infrastructure programmes involve large-scale changes to create value and deliver effective results beyond individual project performances. Therefore, programme typically runs for an extended

duration allowing contextual changes and prioritizing flexibility and emergent strategies
4. Projects within infrastructure programmes can run parallel or sequential
5. Infrastructure programmes focus on stakeholders, benefits, and governance. Complexity arises from these three elements, as examples: technical and societal demand, limited budget, changing environment, and multiple stakeholders
6. Infrastructure programmes have dedicated programme organizations that coordinate and collaboratively manage resources between projects within programme, distribute risks, and address the demands of multiple institutional environments
7. Coopetition (cooperative competition) exists within infrastructure programmes, requiring cooperation among projects within programme to achieve mutual organizational and project objectives
8. Projects within programme has repetitive character as a result of grouping projects and this helps to accelerate learning between projects
9. Infrastructure programmes follow iterative life cycles based on learning, that enable organizational and project-level improvements
10. Programmes in infrastructure facilitate innovation through cooperation, knowledge transfer, resource and technology sharing

Innovation in infrastructure programme
Due to the broad definition of innovation, it is necessary to provide a clear definition of innovation for this research. Based on Section 2.2, innovation in infrastructure refers to the creation of new or improved products and processes that aim to generate long-term benefits for a company which involves various actors such as the government, knowledge institutions, and companies. Engineering companies and contractors, operating on a project-based model, have a vital role in connecting the supply and demand of innovation. They act as a system integrator in the innovation process within the construction field, they oversee, integrate, distribute, and actively contribute to the development and production of innovation. Their value lies in seamlessly incorporating innovation into project design and execution.

From Section 2.3, innovations in infrastructure are typically developed and implemented at the project's level. The motivations to use innovations in the context of infrastructure projects and programmes are diverse and can be attributed to project-related, companies-related, and sector-related factors. In general, innovations are needed in the infrastructure industry due to the increasing complexity of infrastructure projects and societal challenges such as circularity and sustainability.

- Project-related drivers: Innovation in infrastructure projects can be driven by the demand for high-quality infrastructure from public clients, improving project performance, increasing project complexity, and seeking efficiency in organizing and executing projects
- Companies-related drivers: Companies innovate for better performance, competitiveness, and profitability, influenced by culture, policies, leadership, knowledge networks, and corporate image
- Sector-related drivers: Infrastructure innovation is driven by design trends, public client rewards, and innovation-related policies and regulations.

This indicates a positive correlation to why innovation is also needed in the infrastructure programme. The programme's goals heavily influence innovation in infrastructure programmes. The programme goals are translated into project goals within the infrastructure programme. Innovations in compliance-oriented and vision-lead programmes contribute to delivering projects and improving infrastructure quality, effectiveness, and efficiency. Programme also necessitates standardization and tailored solutions to ensure predictable operation and maintenance of water assets. This necessity is only can be fulfilled by innovation. In short, embracing innovation is essential not only for the sector's growth and success, but as well multi-projects such as the infrastructure programme, enabling it to tackle challenges, improve performance, and meet the demands of society effectively.

As depicted in Figure 2.5, innovations in infrastructure are motivated as a result of drivers of innovations and the process starts with the availability of inputs for innovations. However, before investments are made in innovation, preconditions must be present. In the development and implementation of innovations, indicated by the TRL level, barriers in projects, are found and enablers shall help to overcome the barriers. In Section 2.4, there are 27 barriers and 21 enablers found in the projects' literature

which are categorized into seven categories: Contract and regulation, financial, collaboration and cultural, technical, knowledge sharing, client-related and market-related. Table 2.5 shows the list of these barriers and enablers. The barriers to innovation are rooted majority due to project-based settings, as a typical approach in the infrastructure sector. The barriers and enablers found in the literature are found in projects, and therefore not specific to multi-projects within infrastructure programme. Section 2.5 describes a typical process for the government to procure innovation to provide understanding related to the contract and regulation-related barriers and enablers categories.

Theoretical framework

Table 2.7 summarizes the important chosen topics covered in this literature section where the focus is given to the innovation development and implementation of multi-projects within the infrastructure programme. As depicted in Figure 2.3, according to Shehu and Akintoye (2010), six stages are needed to increase the change of programme success. Together with the programme life cycle as seen in Figure 2.2, these six stages are used as a basic foundation for the preliminary framework for the development and implementation of innovation in programme. In combination with the framework of innovations based on Ozorhon et al. (2010) and Xue et al. (2014), a framework illustrated in Figure 2.6 is created.

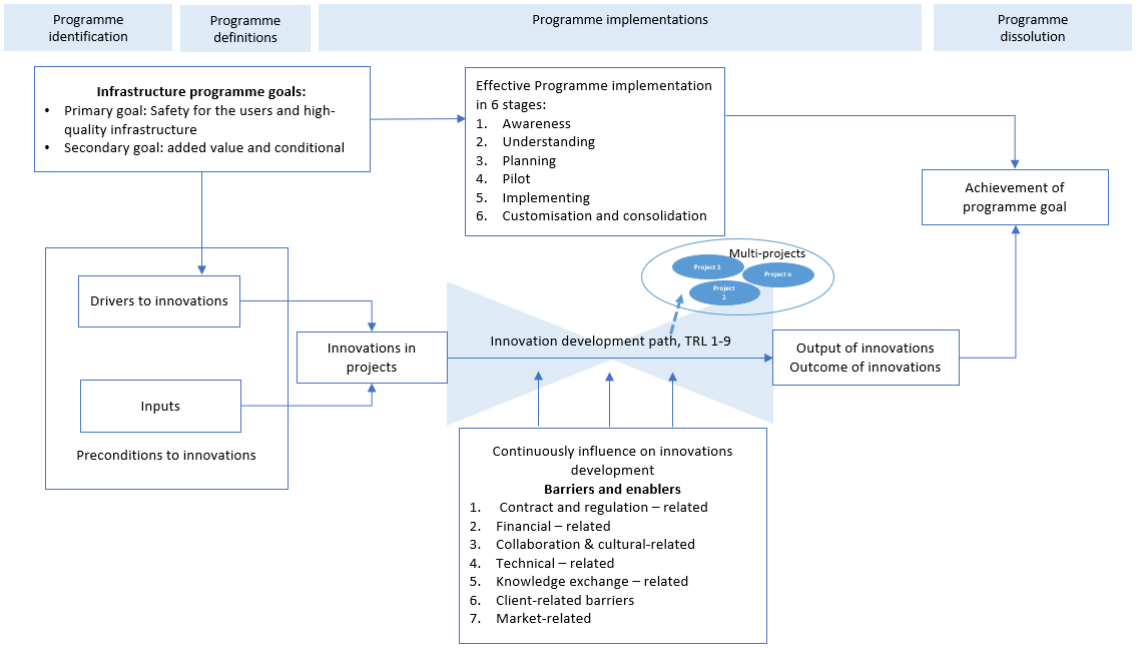

Figure 2.6: Preliminary framework Innov-Infra Framework (own figure)

Next steps

As has been mentioned earlier the majority of the literature provides aspects that influence innovations development and implementation in projects without considering programme context. The 27 barriers and 21 enablers found in this section are project-based perspectives, therefore, lacking relevance with the infrastructure programme. A case study is therefore needed to find the barriers and enablers in the multi-projects within the infrastructure programme. The next chapter will describe the case study selection using the criteria found in this section. The seven categories of barriers and enablers made in this chapter are will consistently thread through this study as overarching themes. These themes are Contract and regulation, financial, collaboration and cultural, technical, knowledge sharing, client-related and market-related. In addition, a method for data analysis will be explained. This will encompass the approach to document analysis as well as the techniques employed to process the outcomes of semi-structured interviews. These steps are crucial in generating valuable insights aimed at designing a practical framework.

Table 2.7: Overview of innovation in infrastructure programme based on literature (Own table)

Topics	Short Summary
Programme lifecycle	In general programme lifecycles consist of programme initiations, programme implementations, programme dissolutions
Programme implementation framework	Six stages of successful programme implementations: awareness, understanding, planning, piloting, implementing, customization and consolidation
Drivers to innovation in projects	Innovations are motivated in projects due to the following needs: Demand to deliver a high-quality infrastructure A necessity to improve project performance Improve companies' performance Gain competitive advantage Gain knowledge and networks Increase corporate image Following the market development (trends) Availability of a rewards scheme
Drivers to innovation in programme	Innovations are needed in programme: To increase the quality of infrastructure To deliver the desired effectiveness and efficiency To achieve the required scalability through standardization
Innovation preconditions	Factors that must be true before the innovation process can begin: Collaboration between actors which consists of inter-organizational cooperation (include cross-sectoral), academia-industry cooperation, complex product systems The presence of culture in an organization which influence by leadership and team
Innovation inputs	Required inputs for innovations Capital resources (financial resources, human resources, knowledge) Information and communications
Innovation enablers barriers	Seven categories of enablers and barriers of innovations: 1. Contract and regulation 2. Financial 3. Collaboration and cultural-related 4. Technical 5. Knowledge exchange 6. Client-related barriers 7. Market-related These seven categories are interrelated and therefore strongly influence one another. Contract and regulation and client-related categories are the top two categories that highly influence collaboration, knowledge exchange, financial, and market. The collaboration and knowledge exchange influence the technical-related. These barriers and enablers are not programme specific. However, since innovations are implemented in projects within programme, these barriers and enablers may application to programme context.
Innovation output and outcome	Output is a direct and measurable results of innovations, such as products, technology, intellectual property, and patents. The output of innovation in programme context is standardized assets. Outcome is impacts resulting from the output. The expected outcome of using innovations in programme is improving the quality of infrastructure assets, achieving the desired effectiveness and efficiency, and enhancing the availability, reliability, and predictability of the assets

3

Case study preparation and data analysis method

This chapter aims to describe the case study preparation for this research. This research employs in-depth qualitative research using case studies where three case studies are utilized to enhance the analytical benefits of the research. Furthermore, a thematic analysis method is used to examine and analyze the selected case studies.

This chapter is structured as follows: Section 3.1 focuses on case preparation where the selection of cases is made and the description of the case study is provided. Section 3.2 outlines the process of collecting data through documents and semi-structured interviews. Section 3.3 explains the methodology employed for data processing and analysis.

3.1. Case Study Preparation

A good preparation of a case study is closely related to the reliability of the research (Yin, 2009). The research question and sub-research questions have been prepared in Chapter 1 and the necessary theoretical background has been gained in Chapter 2. The next step is to select cases to be examined. This research follows a recommendation from Yin (2009) where a multiple-case study is chosen compared to a single-case in order to produce research with a strong effect. The case studies are used in this research to produce an analytic generalization based on the theory of innovation process in the infrastructure industry and to compare with the empirical result of the case study (Yin, 2009)

3.1.1. Case selection

In qualitative research utilizing a case study approach, case selection is a crucial step that involves a screening procedure to ensure the suitability of cases for formal data collection (Yin, 2009). To avoid selecting unsuitable cases for the research, two rounds of basic screening are carried out to identify projects/programme before applying the selection criteria for the case study.

Given that the company where the research was conducted was predetermined, the researcher has access to information on the projects where the company was involved. This implies that the projects are in infrastructure in the Netherlands and the government is the client. The first round of screening began with searching the infrastructure programme. The next step involved identifying whether innovation was employed in the programme, resulting in the identification of one viable case. Due to the scarcity of cases and limited information about the programme within the company, the second round of screening was performed. This involved a search for (multi) projects that utilized innovation, resulting in several cases of projects with various innovation types categorized according to Lenderink et al. (2022) as discussed in Section 2.5. The majority of these innovations were categorized as either incremental or substantial. Next, it was verified if these projects were part of the infrastructure programme. Once the case selection had been narrowed down, a set of selection criteria was applied to the results of both screening rounds. The case screening procedure can be seen in Appendix B.

Based on the theoretical background on infrastructure programme and innovation in Chapter 2, the case selection criteria are determined for this research and these are:

1. Fit in the definition of programme
   This research uses the definition of programme based on the literature, as an integrated, structured framework that coordinates, aligns, and allocates resources, plans, executes, and manages a number of related construction projects to achieve optimum benefits that cannot be realized if the projects are managed separately (Shehu & Akintoye, 2009). This definition should clarify what a programme is and it typically consists of interrelated projects that share resources. Sharing resources between projects can be indicated by sharing technology, tools, human resources, and knowledge. In addition, section 2.1 has explained the difference between multi-projects and portfolios as well the characteristics of the infrastructure programme. This theoretical background helps to identify infrastructure programme.
2. Primary goal and secondary goals are identified in infrastructure programme
   The primary goal is typically driven by compliance with safety but also can be a realization of the government's vision. The secondary goals help the realization of the primary goal but also can arise due to the opportunity to add value.
3. Compliance type or vision-led type of programme
   In relation to the goals, based on the literature, infrastructure programme are typically motivated by compliance with legislation (OGC, 2011). However, an infrastructure programme is also created to realize the government's vision. A mix between these two types of programme is expected to be seen in the practice. This fit into the categorization of programme based on OGC (2011) as seen in Figure 2.3
4. Programme is a large-scale and long duration
   Due to the collection of infrastructure projects within it, programme is large-scale. In addition, the infrastructure programme is long duration. The long duration in this research context is more than four years as a typical duration of framework agreement based on EU procurement law.
5. Programme is a complex endeavor
   In addition to large scale and long duration, the infrastructure programme is complex not only due to inter-relatedness between projects but programme also focuses on the stakeholders' benefit and governing the programme. Satisfying stakeholders' benefits over a long period of time are not only challenging but also determines the success of the programme.
6. Centrally coordinated by programme organization
   Programme organizations must be present to execute the programme and coordinate the resources between projects, distribute risk, and address the multiple stakeholders' demands. Multiple contractors' project organizations exist under a programme organization. A set of functions such as programme director and manager are created to govern the multi-project organization within programme.
7. Complete procurement for projects and/or start development or implementation of innovations in projects
   Programme initiation must have been completed and the projects must be established to deliver the programmes goal. This means that multiple projects have also been tendered where the demand for innovation is expressed (can be implicit or explicit). For example, the need to achieve efficiency and effectiveness is being asked. This demand is translated as using innovation to achieve efficiency and effectiveness by the suppliers. In addition, the tender has been completed and the implementation of innovation is less than 5 years. The reason is the chance that the projects are still ongoing and therefore information can be collected and the people who are involved in the programme still have a clear opinion about the programme and are available for interviews
8. Innovations are developed and implemented in the multi-project
   Since this research aims to investigate the development and implementation of innovation in infrastructure programme, innovations either are developed during the programme or directly implemented in the multi-projects. Based on the literature study, innovation is defined as a new or improved product and/or process or combination of them that differs significantly from the firm's previous innovation and that has been made available to a product or brought into the use of the firm to improve productivity and firms effectiveness that aims to generate long-term benefit to the firm (OECD & Eurostat, 2018). The newness of innovation in this research context is applied in the multi-project setting either as part of the programme's objective or rise during

the programme execution. The type of innovations implemented in multi-projects can be either product and/or innovations, based on categorization seen in Table 2.4

3.1.2. Case Description

Based on the defined criteria to identify a case study, three cases are selected for this research. This section describes the three selected case studies.

Bridges and Quay Wall Renovation Programme (BQWP)
Numerous bridges and quay walls in Amsterdam, exhibit evident signs of poor maintenance and reached the end of their technical and functional lifespan. The Amsterdam Bridges and Quay Wall Programme is initiated by the municipality of Amsterdam to either renovate or replace the city's 850 bridges and 215 km of quay walls that do not meet safety criteria and, therefore could endanger the users. Some of the reasons are that these bridges and quay walls are not designed for the current heavy loads and use, and the majority are overdue maintenance (Amsterdam, 2022). The programme started in 2013 and is expected to continue until 2050, with an estimated budget of 3.5 billion euros. The municipality acknowledges the need for innovation in this programme due to its complexity which is contributed not only by the scale of operation but also its connection to the surrounding environment, the balance between socio-economic consideration, the preservation of the original structure, and the impact on cultural heritage preservation and utilization. To accelerate this operation, both technical and process innovation are required. The traditional methods of renovating the assets would take significantly longer, hence requiring new technical solutions and construction methods. This would also require a different monitoring approach, adjustment of technical standards, and calculation methods to assess the current assets. In addition, process-related changes are needed to govern the internal process, and interactions with market participants, as well as stakeholders. It is the municipality's ambition to accelerate the BQWP by a factor of twenty (Amsterdam, 2022).

To organize this programme, renovation works are divided into groups of projects such as bridge renovation and Quay Wall Renovation (QWR). In the renewal work of the quay wall, two parallel ways to renovate are organized. One group performs renovation in the "traditional way", and the other group works under the Innovation Partnership Quay wall (IPQ). The combination of RHDHV and BAM, a Dutch major construction company is one of the three market combinations that work under the IPQ agreement. The Innovation Partnerships (IP) is a procurement approach used by the municipality to find and work with innovative companies and experts to develop sustainable and innovative solutions for the renovation and replacement of the quay walls (Amsterdam, 2022). This means that a dedicated budget is allocated to develop the innovation and realize these projects. This case falls under the criteria of an Innovation-driven programme by Lenderink et al. (2022). The innovation from each group of market participants will be repetitively used to renovate the quay wall in parallel with the traditional way of renovation to reach the efficiency and effectiveness of the operation.

RHDHV and BAM formed a consortium Koningsgracht and developed SAVE innovation (Samen Amsterdamse kademuren VErnieuwen), an innovative method to renovate Amsterdam's quay walls in a way that minimizes the impact on the environment. SAVE innovation within the projects IPQ as part of RQW is the scope of the case study of this research. The approach involves working from the waterside on a small and scale-able construction ponton using minimal equipment and materials (RoyalHasKoningDHV, 2023).

Road Tunnel Renovation Programme (RTR)
The Amsterdam Road Tunnels Programme is a major infrastructure programme initiated by the municipality of Amsterdam. The programme aims to renovate and improve the city's road tunnels, ensuring their safety, functionality, and durability for the future. The programme includes the renovation of four major tunnels, namely the Piet Hein Tunnel, the IJ Tunnel, the Michiel de Ruyter Tunnel, and the Arena Boulevard Tunnel. The project started in 2018 and is expected to continue until 2025 (Amsterdam, 2023b). The renovation includes technical upgrades, such as ventilation, lighting, and fire safety systems, as well as the replacement of the tunnel infrastructure and finishes.

Amsterdam Road Tunnel Renovation programme (RTR) is chosen as an integral approach by the Mu-

nicipality of Amsterdam based on two underlying objectives. The first is to comply with the tunnel legislation at the earliest possible to guarantee safety to the users and increase the availability of the assets (Amsterdam, 2023a). The second objective is to create an effective and uniform asset management and maintenance of city tunnels, that ultimately also will provide safety to the users. The Municipality of Amsterdam as the assets owner, defined the road tunnel area into five road tunnel renovations, a traffic control center, and a transmission network.

The Tunnel Engineering Consultant (TEC), a consortium of consultancy companies including RHDHV, is contracted under a framework agreement to provide technical consultancy for the municipality to reach the aimed efficiency for future operation for the tunnel management and maintenance (Consultant, 2023). The scope of this work is to renovate three tunnels and to develop a new traffic control center to be in full compliance with the legislation and future operation. Under this scope, the consortium utilizes technological innovation advanced BIM/digital tunnel so-called Digital Twin to design the tunnel (PMI, 2023). This innovation is considered incremental innovation/substantial because the BIM technology is not new anymore in the industry. The development and implementation of Digital Twin innovation in Amsterdam's tunnel projects within the RTR is the focus of this case study.

Eight Steel Bridges Renovation (SBR)
The Directorate General for Public Works and Water Management (known as Rijkswaterstaat (RWS)) is the largest public infrastructure asset owner in the Netherlands. To ensure the ongoing availability of the existing infrastructure, RWS regularly organizes large-scale renovation programmes. These programmes encompass the renovation and replacement of bridges, tunnels, sluices, and viaducts. The urgency of the renovation and replacement programme stems from the fact that the majority of the existing assets, built during the 1960s and 1970s, are nearing the end of their technical life (Rijkswaterstaats, 2023b). Within the bridge renovation projects, a specific focus is placed on a group of eight steel bridges. The objectives for renovating these bridges include faster completion, cost-effectiveness, high-quality outcomes, and minimal disruption to traffic. The bridges in question are Muidenbrug, Beek, Scharbergbrug, Galecopperbrug, Tacitusbrug, Kreekrakbrug, Suurhoffbrug, and Brienenoordbrug. These bridges are located within the major road network of the Netherlands (Rijkswaterstaats, 2015).

Prior to the renovation of these eight bridges, in 2006 Rijkswaterstaat conducted thorough research and tested the use of High-Performance Concrete (HPC), which has the potential to extend the lifespan of the bridge decks by 30 years. The successful application of HPC in the initial tests has prompted Rijkswaterstaat to consider implementing it in the renovation of other bridges as well, rather than opting for complete replacement. However, as the application of HPC technology on bridge decks was relatively new, many contractors lacked the necessary competence and experience to effectively utilize HPC. To address this issue, Rijkswaterstaat established a group of renovation projects consisting of eight steel orthotropic bridges to ensure that market participants acquire the required knowledge and capability to execute HPC in future renovation projects. In order to achieve this objective, Rijkswaterstaat appointed a Managing Contractor (MC) composed of RHDHV, Arup, and Greisch, to oversee and facilitate the smooth implementation of HPC within the SBR initiative (Rijkswaterstaats, 2015). The renovation of these bridges began in 2009. In 2017, the six bridges were completed the renovation projects. This renovation project is still ongoing and expected to be completed in 2028 (Rijkswaterstaats, 2023a). The HPC innovation implementation in the SBR projects is the focus of this case study.

3.2. Data Collection

This section explains the data collection process as part of the empirical study of this research. Two data types are collected for qualitative analysis; document and semi-structured interviews. The objective of collecting these data is to identify the barriers and enablers of the development and implementation of innovation in practice and other innovation elements.

3.2.1. Data document

The documents that are included for the data document analysis come from an internal and external company. These documents contain implicit and explicit information about the barriers and enablers of innovations. Findings from the documents are combined with the findings from semi-structured

interviews. The two types of data documents collected and reviewed are:

- Public documents
  Most of the information about the programmes from government bodies in the Netherlands is publicly available via official websites. The documents retrieved from the official websites provide background information about the approach of public clients to the programme.
- Company internal documents
  The internal company documents needed for this research are the project documents containing information about the innovations such as the tender documents, progress reports, and presentations. In these documents, the information about the development or implementation of innovations is implicit or explicitly expressed. This is especially important for innovation in the category of Innovation-friendly or Innovation-oriented procurement as seen in Table 2.6.

3.2.2. Semi-structured interview

After the documents were reviewed, semi-structured interviews were conducted as part of the empirical study. As this research aims to gain insight into innovation in a multi-project setting, obtaining the meaning of individuals who are involved in the case study through interviews will be valuable to the research. Through the semi-structured interview, barriers, and enablers to innovations together with other innovation elements were expected to be found. This is done by asking open questions instead of structured or non-structured interview questions because they have the potential to provide more detailed information through follow-up questions (Creswell, 2014). This method allows the researcher to collaborate with the interviewees where the meaning of the interviewees is collected during the interview and combined with the researchers personal values and the concept gained from the literature study (Verschuren & Doorewaard, 2010). The outcome of the interview can help validate the findings from the literature and discover factors that contribute to the development and implementation of innovation. This section also discusses the interviewee selection process and the protocol for the interview.

Criteria for interviewee selection

For selecting the interviewees, a set of criteria was determined. One, the interviewees are key personnel in the identified selected case from Section 3.1. This includes personnel from the Engineering company, contractors, and their partners that are involved in the development and implementation of innovation. This involves the project managers/leaders, programme managers, and technical managers from these companies. Second, interviewees shall have experience in the infrastructure programme for at least the last five years in their position. Third, the interviewees should be directly involved in the multi-project within programmes that utilize the innovation. Lastly, there should be a variation of function in the case study to gain various perspectives on the implementation of innovations. This means that it is preferable to have a set of interviewees per case that consists of project managers, technical managers, and partners/suppliers. The profile of the interviewees is depicted in Table 3.1. In addition, a minimum of three interviewees is identified per case study to reach the data saturation points where the collection of data from the interviews no longer yields additional insight, as well as increase the credibility of the research (Saunders et al., 2009).

Table 3.1: Overview of selected interviewee

Case study	Category	Actor Code	Role	Date of interview
1. QWR	Engineering Company	R1QWR	Project Manager/Leader	13/Jun/23
2. QWR	Engineering Company	R2QWR	Technical Manager	14/Jun/23
3. QWR	Partner Contractor	P1QWR	Project Manager/Leader	20/Jun/23
4. RTR	Engineering Company	R1RTR	Technical Manager	05/Jun/23
5. RTR	Engineering Company	R2RTR	Project Manager/Leader	19/Jun/23
6. RTR	Partner Engineering Company	P1RTR	Project Manager/Leader	12/Jun/23
7. SBR	Engineering Company	R1SBR1	Technical Manager	21/Jun/23
8. SBR	Contractor	C1SBR2	Project Manager/Leader	22/Jun/23
9. SBR	Contractor	C2SBR3	Project Manager/Leader	14/Jul/23
10. SBR	Engineering Company	R2SBR1	Project Manager/Leader	17/Jul/23
11. SBR	Engineering Company	R3SBR1	Project Manager/Leader	21/Jul/23

In total eleven interviewees were selected and codes were assigned to the programme case study and the interviewees. The interview codes were assigned based on the companies and the case. The interviewees' experience ranges from five to 35 years.

Interview preparation
Before conducting an interview, official requests were made via email. This included a description of the research topic and the objectives of the interview, as seen in Appendix D. The interviews were scheduled based on the availability of the interviewees. Alongside the request, informed consent forms were sent to the interviewees, outlining the data management procedures for the interviews. This included obtaining agreement from the interviewees regarding audio recording and transcription of the interviews. The interviews were conducted either online or in person, depending on the geographic location of the interviewees. In addition, the interviews were conducted and transcribed anonymously in Dutch before conducting further analysis for this research. The transcriptions were sent to the interviewees upon their requests and the results were shared with them.

Interview protocol
In order to conduct an effective interview, the interview protocol is prepared as a guide for the interviewer. The 60-minute interview was divided into six parts and organized based on themes. The themes were formed based on the literature study in Chapter 2. These are general understanding, barriers to innovations, enablers of innovations, and preconditions of innovations.

The interviewees were made aware of these themes at the beginning of the interview. The interview started with an introduction of the researcher and the interviewees in Part I, and the interviewer addressed the purpose of the interview and the research. In this part, the interviewer was made aware of the confidentiality and the recording of the interview as stated in the informed consent form that was sent prior to the interview. Part II contained basic information and a general understanding of the programme, innovation, and the relation of innovation in the infrastructure context. This part served as ice-breaker questions as suggested by Creswell (2014). In this section, the interviewees were asked about the motivations of their companies to innovate in the case study's projects. Part III focused on barriers and their related issue by using the categorization formed in Section 2.4, and it was followed by Part IV regarding the enablers of innovation. In Part V, the interviewees were asked about the impact and precondition of innovations in the programme, and Part VI concludes the interview.

The protocol and the questions can be read in Appendix D. Each interview was expected to be completed in a maximum of 60 minutes with a 10-minute safety buffer. The majority of the questions asked the opinion of the interviewees on a specific topic. The yes/no questions were sometimes asked and were accompanied by follow-up questions for further explanation from the interviewees.

3.3. Methodology of data analysis and interpretation

As part of qualitative analysis, a thematic analysis for the case study was employed in this research. The thematic analysis provides systematic and visible methods and procedures to achieve the research goal. It is done through search carefully the collected data, identifying patterns, methodically coding, generating themes, and developing a story (Creswell, 2014). The analysis is an iterative process performed by the researcher through a continuous interpretation of the data (Creswell, 2014). The analysis process is depicted in Figure 3.1 below and explained in the following steps.

Part I - Data document analysis

1. Data organizing and preparation for analysis. The data (project) documents are collected and organized by assigning code to each of the documents for identification. The list of data documents with the assigned codes can be found in Appendix C. The recorded interviews are transcribed word for word before proceeding to qualitative data analysis.
2. Reading the data. The project documents are read thoroughly and extract information related to the understanding of the innovation process in the projects such as technical and development of innovations, collaboration process, and financial concerns.

3. Interpretations are performed once the documents are read. For example, when various changes are made to the design may indicate technical challenges or changes based on clients' requests.
4. Once the interpretation is done, codes and themes that were made earlier, are assigned to them in order to organize the data presentation on the report. The theme for the data document is using the categorization found in the literature review with additional themes that may arise during the data analysis. The list of codes and themes can be found in Appendix E. The output of data document analysis is the elements of the innovation process such as drivers, inputs, enablers, and barriers to innovations.

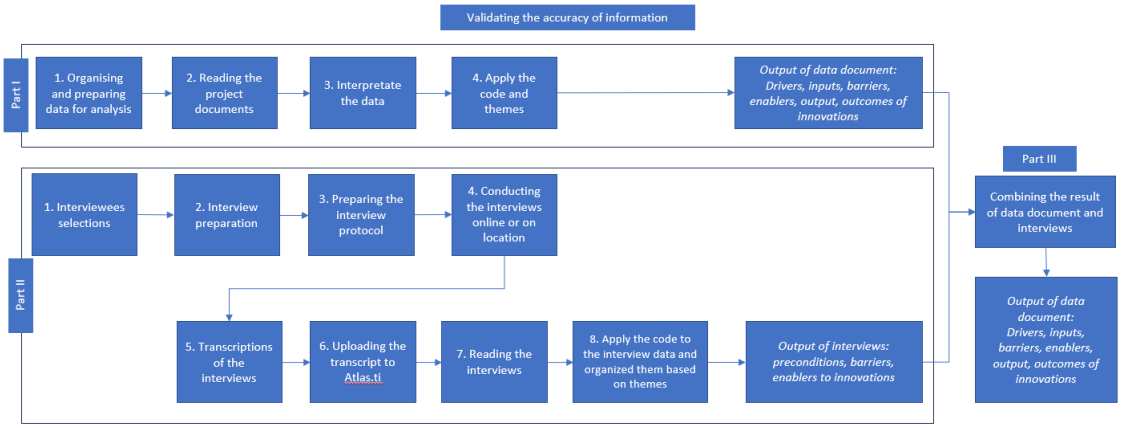

Figure 3.1: Data analysis process modified from Creswell (2014) (own figure)

Part II semi-structured interviews

1. Interviewees selection. Before semi-structured interviews are conducted, interviewees are identified and selected based on the criteria made in Section 3.2.2
2. Sending official requests to the interviewees. Interview requests are sent via email. Requests about the date and time of interviews are also made in this step. Once agreed, the informed consent form is sent to the interviewees before conducting the interviews. This step is explained in Section 3.2.2
3. Preparing interview protocol to ensure a swift interview process and consistency of the questions. This step has been described in Section 3.2.2
4. Conducting interviews. The interviews are conducted online via Teams or on location. The audio recordings are also made by the interviewer during the interviews, after the interviewees' agreement. The interviews are conducted in the Dutch language as agreed with the interviewees.
5. Generating transcription of the interview and editing process. Transcripts of the interviewees are made and (grammar) edited carefully before further data processing
6. Uploading data to Atlas.ti. The transcriptions of the interviews acquired in the previous step are added to the software Atlas.ti before further applying the code. Atlas.ti is a common tool in academic research in social science to help structure an extensive qualitative data analysis such as interviews where the researcher could assign codes, assign and retrieve quotes, and draw correlations between codes (Hwang, 2008).
7. Reading through the interview transcriptions. In the interview transcription, elements such as characteristics of programme, the relevance of innovations in multi-projects, barriers, and enablers, and preconditions are scanned and interpreted by the researcher. This step helps to gain a thorough understanding of the content and the context of the data. The codes and themes, found in Appendix E, are applied. Applying codes and themes is an iterative process, therefore there is a possibility that new codes and themes will be created based on the transcripts of the interviews. This iterative process is performed to ensure the analysis is comprehensive and yields a clear, accurate, and unambiguous interpretation of the data before finally capturing the essence of the research question.

8. Analyzing the interview. A thorough analysis is performed for every coded data and assigned theme. The themes are interconnected to build qualitative narratives to convey the findings of the case study analysis. The output of the semi-structured interviews are preconditions, enablers, and barriers to innovations in infrastructure programmes.

An example of applying code in Atlas, can be seen in Figure 3.2 below.

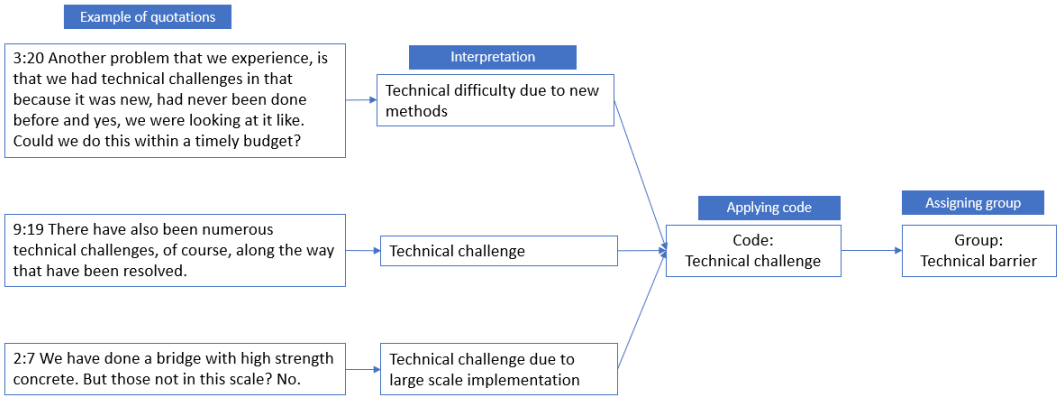

Figure 3.2: Example of coding process (own figure)

Applying codes and categorizing them in themes results in a series of codes as seen in Figure 3.3

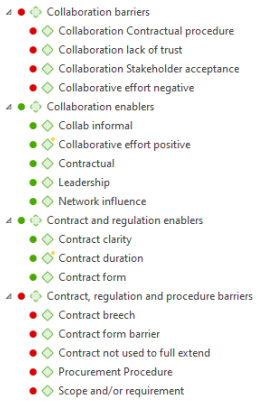

Figure 3.3: Example of codes and themes developed in Atlas.ti (own figure)

Part III - Combining the results
The third part combines the result of data document analysis and interviews. Presenting the result of the analysis in the report per case study before making comparisons and generalizations. Per case, the result of the data document interpretation is presented separately from the result of interviews. The output of this analysis will be innovation elements such as barriers, enablers, and contributing factors that influence the development and implementation of innovations in the infrastructure programme based on the researchers interpretation of the data.

The results from data analysis and interviews from each case study are presented in the next Chapter. The outputs are used to develop solutions to accelerate the development of innovations in order to contribute to the programme's objective.

4

Case Study Result and Analysis

This chapter contains findings and analysis after qualitative data analysis is carried out by reviewing the project documents and conducting semi-structured interviews of three case studies selected in Chapter 3. The objective of this chapter aims to provide the answer for SQR4: *What are barriers and enablers to innovations identified in programme?*

This chapter is organized as follows: Section 4.1, Section 4.2, and Section 4.3 present findings from each case study. Each of these sections consists of the analysis of innovation elements including barriers, enablers, and pre-conditions. The detailed analysis of the case study can be found in Appendix F. The barriers and enablers presented are organized based on the themes as indicated in Appendix E. Section 4.4 focuses on the comparison between the three cases, Section 4.5 presents the general results, and Section 4.6 conclusion of the case study.

Section 4.1 until section 4.3 contains two types of analysis, therefore are presented in two parts. The first part of the section presents the findings from the data documents and the second part is the result from semi-structured interviews. The documents reviewed in this section are assigned a unique code, therefore, any quotations coming from these documents are referred to these codes to ensure their traceability. The list of these documents with their codes can be seen in Appendix C and the complete analysis of the documents can be seen in Appendix F. Similarly, codes are also assigned to the interviewees as indicated in Table 3.1. The innovation elements are organized in the same category as seen in Section 2.3.

4.1. Case Quay Wall Renovation (QWR)

4.1.1. QWR document review

Enablers and barriers from documents

From various project documents, a set of enablers and barriers are identified until the current stage of innovation development. The following barriers are found:

- As indicated in programme progress report 2023, programme budget is annually reduced based on the coalition agreement [IPQ5]. This further results in adjustments made to the programme organization and programmes goal
- Based on the political decision, the budget for the programme is reduced to half while the municipality also understands that the availability of sufficient budget is needed to realize the objectives and scale up the production [IPQ5]
- The requirements on the projects are difficult to achieve [IPQ8] and costly to realize, such as strict requirements around monumental value and preservation of trees. These requirements are not only costly but also result in the allocated budget being spent earlier than the plan [IPQ5]
- As a result of the budget reduction, the programme organization was forced to shrink. This situation will influence the capability of programme organization and the continuity of knowledge [IPQ5]. Although it was also argued, that a smaller team would allow for greater emphasis on selecting individuals with the right qualifications and specialized knowledge for the tasks at hand, thereby improving overall quality [IPQ5]

- The budget reduction influences the relation with market parties where the expected volume of works is reduced from the agreement [IPQ5]
- Due to the long validation process from one phase to another phase, a delay occurred in the realization of the pilot phase [IPQ5]
- The chance of quay wall collapse and what kind of collapse mechanism of the quay wall is not known. This makes the risk higher implementation of the innovation is also difficult [IPQ7]. In addition, due to technical difficulty, some of the element desired in the design is not applicable [IPQ8]
- The price of materials increased due to the effect of the COVID-19 crisis and influenced the estimated price/km of renovation [IPQ5]. IPQ started in 2019, before the COVID-19 crisis.

The enablers of innovation in QWR are:

- The municipality expressed its continuous commitment to support the programme and programme organization, as indicated in the progress report 2023 [IPQ5]
- As a result of the political coalition agreement in 2018, a programmatic approach was chosen to bundle projects in the renovation of the quay wall [IPQ14]
- In the development of innovation, using the known technique adopted from other sectors, contributes to reducing the uncertainty in innovation [IPQ3]
- In addition, using knowledge of the latest technology such as the parametric design allows further optimization of the design [IPQ3]
- The technological risk reduces throughout the time between phases of innovation due to a better understanding of the context, technology, and surrounding [IPQ7]
- Knowledge sharing is encouraged between parties in the programme through market communities facilitated by the programme organization [IPQ12]
- The three IPQ market combinations propose a plan to utilize an innovation platform that facilitates the execution phase such as sharing resources, transport, and hub [IPQ7]. However, the realization of this plan is not yet clear until the pilot phase is completed.
- IP, combining the development of innovation with the procurement of innovation, enables the client to contract at large volume and enter a long-term collaboration with market parties by using a framework agreement [IPQ1]

Summary of document review QWR
BQWP can be described as a complex, multi-year renovation programme that consists of various projects and groups of projects of renovation bridges and quay walls, centrally coordinated by programme organization created by the municipality of Amsterdam. The underlying reason for programme creation is to create synergy between projects that run in parallel and series to speed up renovation works. Satisfying stakeholders' benefits is crucial in BQWP. IPQ is part of QWR where the municipality entered an agreement with three market parties combination to develop innovation before implementing the result of the development in a series of renovation projects. It enables the client to contract the companies for a high volume of renovation work. Innovations in IPQ undergo a development path from TRL 1 until TRL 9, where innovations reach a commercialized phase and are ready for implementation on a large scale. In this research, the focus is given to the SAVE innovation, developed by a combination of market parties BAM and RHDHV, in a so-called combination Koningsgracht.

Based on the project document review, the following elements in relation to SAVE innovation were found and summarized in Table 4.1. A detailed analysis of the QWR programme and the innovation process can be found in Appendix F.1.

Table 4.1: Findings from document review QWR

Innovation elements	Descriptions
Drivers	Expedite the renovation of quay walls with minimum hindrance, short lead time, solutions that are widely applicable, and low cost
Inputs	Dedicated budget for innovation are available through IP, part of programme budget Large volume of renovation works
Enablers	**Contract and Regulation-related** IP enables the client to contract at large volume and enter a long-term collaboration with market parties by using a development agreement and framework agreement after innovations are successfully developed
	Collaboration and Cultural-related Creation of market community by programme organization to facilitate the knowledge exchange Initiative from three IPQ market combinations to utilize innovation platform that facilitates cooperation (still plan)
	Technical-related The technological risk reduces throughout the time between phases of innovation due to a better understanding of the context, technology, and surroundings, as well the use of parametric design
	Client-related The municipality indicated a continuous commitment to support the programme& programme organization As a result of the political coalition agreement in 2018, a programmatic approach was chosen to bundle projects in the renovation of the quay wall
Barriers	**Financial-related** Reduction of programme budget influences the innovations' budget
	Collaboration and Cultural-related The relationship between programme organization and market parties is negatively influenced due to budget cut
	Technical-related Implementation of innovation is difficult due to uncertainty and the adjustment of the design is therefore required
	Client-related Based coalition agreement, the budget is reduced. Although the municipality also understands that a sufficient budget is required to realize the programme objectives Strick requirements and demand of internal stakeholders are costly, resulting in early budget depletion programme organization is shrunken which results in a reduction of organization capacity and influences the knowledge continuity
	Market-related Covid-19 crisis influences the price of materials and therefore influences the initial estimated price/km of renovation works
Output	Innovation as a technology to renovate quay wall Intellectual property for the developed innovation
Outcome	Faster renovation of quay wall Less hindrance to surrounding Low cost Widely applicable to other quay wall renovation

4.1.2. QWR Semi-structured interview

Barriers to innovation in QWR

From the interviews, 11 barriers were identified. These 11 barriers are further categorized into contract, regulation, and procedure-related barriers, client-related barriers, time barriers, technical challenges, financial-related barriers, and collaboration barriers.

- **Contract and regulation barriers**
  The primary obstacles faced in QWR are contract-related barriers, specifically related to the scope and requirements, as well as the contract form. Market participants perceive the IP procedure and contract form as hindrances to the development of innovation. This issue is particularly critical during the procurement phase, where innovations need to be developed starting from a low TRL. Unclear requirements stated in the request for proposal, coupled with limited time for confirmation, have led market participants to rely on their own interpretations [P1QWR, R2QWR]. Interviewee R2QWR mentioned, ”During the procurement phase, you have relatively little time, then you also have to immediately make your own interpretations of how you think what’s in the contract or in the solicitation is, how that’s intended”. Consequently, assumptions are made regarding these requirements, which significantly impact the subsequent development of innovations. It is imperative to address this challenge as it directly affects the later phases of innovation development.

  During the procurement phase, limited interaction with the public commissioning (public client) is a noteworthy issue, particularly in the IP process where the innovation must be developed according to the client’s wishes. According to the interviewee QWR2 ”In particular, discussions about that are very limiting to the progress of the project” and interviewee P1QWR mentioned, ”We didn’t know what the customer wanted, so it wasn’t clear what they wanted”. However, the level of engagement with public commissioning improves during the R& D phase as indicated by R2QWR. The interviewee mentioned that ”During the process at the end of the pre-designed, you notice that the distance with the client is becoming smaller and smaller because the clients are looking for a lot of consultation, they have simply been present”. Moreover, stringent and overly detailed requirements can impede innovation by acting as barriers. As mentioned by P1QWR ”so some requirements were very high level of really super conceptual and others were very detailed and that differs in requirements”, and similarly R1QWR also mentioned ”Stakeholders are quite strict on their requirements and the client can say, well, this is just a requirement from a stakeholder that landed in the contract. You have to comply with that and approach the stakeholders and bring the client along”. These requirements are often demanded by stakeholders who significantly influence the programme [R1QWR, R2QWR, P1QWR].

- **Client-related barriers**
  Closely related to the contractual-related barrier is the client organization size and/or structure and their demands. The municipality of Amsterdam has an organization size in comparison with other municipalities in the Netherlands. The programme organization is highly influenced by stakeholders from its internal organization who demand certain mandatory requirements [R1QWR, R2QWR]. The interviews also revealed that the structure of the client’s organization hinders the decision process related to the programme. Although there is a dedicated programme organization and a dedicated position that deals directly with the market participants, the influence of some internal stakeholders within the Municipality is dominant. As an example, there is a separate function in the municipality that decides the budgeting [P1QWR]. In addition, as a government organization, the programme is highly influenced by politics, as mentioned by R1QWR ”Sometimes a choice has to be made that has to be made at two levels higher in the organization” and it becomes an obstacle to get the client on board, as mentioned by R2QWR ”that is very difficult to get a good grip on them and to ensure that they also go along with the plans you have as a party”.

  In addition to the client-related barrier, due to the various internal stakeholders in the municipality, it is noticeable that there is a conflict between programme’s goal and other requirements [R2QWR, P1QWR]. As an example R2QWR mentioned ”But you notice that basically, the people

who work there are also just people who also just have to abide by certain rules, and that is just their world". The interviewees indicated that some departments have very strict rules while working on innovations requires a space to maneuver between those rules and not treat them as usual projects. P1QWR mentioned, "For example how many inches something has to be long or wide. That doesn't fit with a request for innovation" and R2QWR also stated "And when you're working on something innovative, then you're always going to nibble a little bit at those rules and the boundaries".

- **Time barrier**
  The interviewees considered the duration of the IP process as a barrier [P1QWR, R1QWR]. Particularly, the R&D phase is described as excessively lengthy, demanding both a significant budget and a substantial workforce. P1QWR indicated that "The Obstacle is that actually every phase took longer than expected" and R1QWR "That also just takes a lot of time, so particularly the time aspect, that's a hindrance". In addition, the interviewee argued that the IP requires a different type of mindset from the internal team due to the long process, as said by P1QWR "Four years of designing and then finally being allowed to build something, is just too long".

- **Technical challenge**
  Technical challenge is one of the barriers to development innovations based on the interviewees. Although other interviewees indicated that technical challenge is part of the innovation [R2QWR], the technical issue is still recognized by the majority of the interviewees as a barrier. For example, R1QWR mentioned, "The scope is to renew the quay wall in an old city center and we come across a lot of things that are not documented or are different, so you do have discrepancies". In addition, although the methods and technology used to develop the innovation are relatively traditional, the application of those methods in QWR is still unknown and, therefore seen as technically challenging [R1QWR]. The interviewee also argued that companies in construction do not own R&D department that develops certain innovations, therefore it is technically challenging to develop innovations in projects [P1QWR].

- **Financial-related barrier**
  Interviews revealed that high innovation costs and the difficulty in internalizing benefits are two major financial barriers. The development of innovation requires a high investment from the market participant. Although through the IP, it is expected that this high cost can be later spread out during the implementation of the innovation, this situation is seen as a barrier from the market participant due to a limit of the internal budget. P1QWR mentioned that "In the world where we work, the margin is super small, so we make very little margin, a few percent. With a few percent, you have much less budget to innovate". This results in technical adjustments and prioritizing must be made to meet the available budget as mentioned by R1QWR "But choices are also made because that cost a lot of money or are too expensive, so we have to think of something else".

  The financial condition of the programme directly impacts the budget allocated to the QWR and IPQ parties. According to the interview, this situation has emerged as an internal financial concern for companies [P1QWR, R1QWR]. P1QWR mentioned, "We have incurred all our costs and now at one time it turns out that the revenue is not guaranteed. That's very damaging". The reduction in volumes of work directly influences the price/meter of the quay renovation since the initial business case of IPQ is no longer valid [R1QWR, P1QWR]. This translates directly to a lower Return on Investment or a longer return needed. Interviewees indicated that this situation becomes the source of other barriers such as a lack of trust [P1QWR].

- **Collaboration and cultural-related barrier**
  It has been mentioned earlier section that the IP procurement procedure has an impact on the innovation process. In relation to this barrier, collaboration with the client is also influenced especially in the early phase, while early collaboration is crucial in the development of innovation to ensure the innovation is suitable for the QWR [R2QWR, P1QWR]. R2QWR said "But the distance is just pretty decent at that point, and again it has to do with the idea you're developing yourself"

and P1QWR added, ”But you have one or two official times where we were allowed to ask questions. So what an obstacle was that we didn’t know if we were going in the right direction”. In addition, collaboration with the internal stakeholders from clients’ organizations is lacking. Each stakeholder required strict requirements that offered no room for discussion. This is seen as a barrier to collaboration by the market party, as indicated by R1QWR ”Of course they have been informed about the IPQ and that we are going to do it differently and build differently. But then at the end goal, they do get the quay wall that they are used to and that they want to manage. But in between there are different parts that are different for a stakeholder”.

Enablers to innovation in QWR
The interviews have revealed that there are five enablers to the development of innovation in QWR: Knowledge exchange internal and external, contract form, and Collaboration and cultural-related which includes collaboration effort and the influence of network.

- **Knowledge exchange-related**
  The knowledge exchange-related enablers are divided into internal and external market participants. In QWR case, internal is within the Konginsgracht combination, and external is outside this organization. The internal knowledge exchange between RHDHV and BAM positively influences the development of SAVE innovation where it is highly influenced by the motivation of these two market parties to form a combination Koningsgracht. Based on the underlying interest to expand and extend their market in Amsterdam [P1QWR, R1QWR, QWR2], these two parties which have previous experience working together, collaborated and formed Koningsgracht combination to acquire work in QWR. To extend collaboration, an exchange of knowledge between these two parties is required and put on priority in the development of innovations, such as indicated by R2QWR ”There is always a bit of interaction in that and I think that will always continue to arise and it is precise because of that interaction that at a certain point in time you can also say that the exchange of knowledge simply comes to life”. Each individual involved in the project brings a positive contribution to the development of innovation by using their experience gained from other projects as mentioned by R1QWR. R2QWR also added, ”I would have also taken a piece of knowledge from that and also brought it into the project”. These two parties work closely together with clearly defined responsibilities.

  External knowledge exchange also contributes to the development of innovation as indicated by the interviewees. As it has been mentioned in Section F.1, the municipality has a dedicated organization function that is actively involved in the development of innovation together with the Koningsgracht combination. Interviewee R1QWR mentioned that ”Occasionally the technical manager from the client’s side would also sit at the table. That was very nice and we were very open with each other so that the client could also see what we were up against”.

- **Contract and regulation-related**
  Contract form is one of the enablers of the development of innovation. The interviewees agree that the IP is a suitable procedure that facilitates the development and implementation of innovations, although it can also act as a barrier. As indicated by P1QWR, IPQ is sensitive to budget change which can badly influence the return on investment made by the companies. Especially in the IPQ, the Municipality contributes to the development of innovation that is not available yet in the market by facilitating the R& D process and providing a sufficient volume of work to ensure the implementation of innovation. R2QWR expressed that the IP possesses fairness because when the innovations are proven work, a certain volume of work is guaranteed. R1QWR supported this by saying ”Well contractually, that’s your risk, this is our risk. It’s not all roses, let me put it that way, but we can deal with a lot of things that are negotiable and for everybody”. This indicated that the contract clarifies risk sharing between the municipality and Koningsgracht and the responsibilities of the parties. This clear separation facilitates the development of innovations.

- **Collaboration and cultural-related**
  The interviewees mentioned two Collaboration and cultural-related factors that enable success. The first factor is a positive collaborative effort, which encompasses internal and external contri-

butions to innovation development and implementation. This includes elements such as transparency and open communication. For instance, establishing good relations with the programme organization can have a positive impact on collaboration, ultimately fostering innovation development [P1QWR]. R1QWR mentioned that although the budget cut occurred, the communication between client and companies are still open. This becomes a unique collaboration between clients and companies. As indicated by R1QWR, "The municipality tells what they are with. We tell what we're with, so there are/will be no surprises. That I find the same with three IPQ combination. So it's kind of unique, how we work together". R2QWR added "What I do think is important is that you have the different teams, because, on the one hand, you have of course the team within us as the contractor. On another side you have a team as the client that there are people in there that kind of fit together, so purely the human factor, so to speak". The second factor that enhances collaboration is the presence of equivalent roles within the programme organization. For example, having a technical manager who closely collaborates with the Koningsgracht combination team promotes effective collaboration and facilitates innovation development [P1QWR].

Network configuration has a positive contribution to the development of innovation. This is also the reason why the BAM and RHDHV decided to form a partnership in IPQ, to work with the known party that has a history [R2QWR, R1QWR]. R1QWR mentioned, "As a company, RHDHV, and BAM have known each other for a long time. We didn't just suddenly find each other but consciously enter into this together". It was indicated as well during the interview that the influence of the network with the third party in innovation is relatively low in comparison between the two partner companies, but it still has a positive contribution to the development of innovation [R2QWR, P1QWR]. It has been mentioned by P1QWR that "So we definitely need outside knowledge to help us and we pay those people or they also go along the innovation" and R2QWR added that "If I look purely at IPQ, actually everything that we developed just happened within BAM and RHDHV. And that also means that you have to rely on a number of people working within those two parties."

Precondition to innovation in QWR

According to the interviewees, three crucial factors contribute to the successful implementation of innovation in QWR. The first factor is the trustworthiness of clients and partners, which plays a pivotal role [R1QWR, R2QWR]. This has been mentioned by R2QWR "And that also means relying on a number of people who are working within those two parties. But those people who are working within those parties, who of course themselves also have all kinds of lines of communication with other companies and parties outside as well" and by R1QWR "That is actually framed in the contract and you have to comply with it, so those are the preconditions, and within that, you can apply your innovation, and sometimes there is some bandwidth in there, some freedom in how it is implemented, interpreted, or nothing is described it". Since innovation involves a lengthy trajectory and collaboration with clients and partners, trust is vital for effective collaboration. The second precondition is that the initial investment should align with the financial capabilities of the companies. It is indicated by P1QWR "If the investment is too big, we (or partner or other parties) don't do it. Thus, the investment also has to do with a business case". A solid business case, therefore, serves as a prerequisite for innovation development. The third factor is the presence of a clearly defined contract. This is necessary to avoid misinterpretation of the contract, which can significantly impact innovation development. R1QWR mentioned "We have to meet all the demand specifications and that has to be scalable, can you pace later, can you speed up or, can you deal with obstacles? That's actually framed in the contract and you have to meet that, so those are the preconditions for innovations". Given the high cost associated with innovation, an incorrect interpretation of requirements can be detrimental to all parties involved.

Summary of interviews in QWR

Based on the interview, the pre-conditions to bring the SAVE innovation into successful implementation in programme are the client and partners' trustworthiness, solid business case, and clearly defined contract requirements. There are 11 barriers identified from the interview and they are categorized as a category in Section 2.4.1. Five enablers of innovations are also revealed from the interviews.

Table 4.2: Summary QWR interviewees

Barriers	Enablers
Contract and regulation related - Contract form barrier	Knowledge sharing related - externally
Contract and regulation related - Scope and/or requirement	Knowledge sharing related - Internal
Client related - Client organization demand	Collaboration and cultural related - positive collaborative efforts
Client related - Client organizational size/structure	Contract and regulation related - contract form
Client related - conflict between goals and requirements	Collaboration and cultural-related - network configuration
Collaboration and cultural-related - contractual procedure	
Contract and regulation related - procurement procedure	
Financial related - innovation cost	
Technical related - technical challenges	
Time barrier	

4.1.3. Summary of QWR Case

Based on the document review and semi-structured interview, the findings can be summarized as seen in Table 4.3. The barriers and enablers that come from documents are coded as D, and the interviews are coded as I.

Table 4.3: Summary QWR

Innovation elements	Descriptions	Source
Drivers	Expedite the renovation of quay walls with minimum hindrance, short lead time, solutions that are widely applicable, and low cost	D
Inputs	Dedicated budget for innovation are available through IP, part of programme budget	D
	Large volume of renovation works	
Preconditions	Trustworthiness of clients and partners	I
	Financial capabilities of companies/organizations	
	Clearly defined contract	
Enablers	**Contract and Regulation-related**	I
	Contract form IP	I
	Collaboration and Cultural-related	
	Positive collaboration effort is indicated such as utilizing meetings to facilitate communication, the presence of transparency, and open communication by clients and market parties (internal and external)	D & I
	Creation of market community by programme organization to facilitate the knowledge exchange	D
	Initiative from three IPQ market combinations to utilize innovation platform that facilitates cooperation (still plan)	D & I
	network configuration	I
	Technical-related	
	The technological risk reduces throughout the time between phases of innovation due to a better understanding of the context, technology, and surroundings, as well the use of parametric design	D& I
	Knowledge sharing-related	
	Knowledge sharing related to external	I
	Knowledge sharing related to internal	I
	Client-related	
	The municipality indicated a continuous commitment to support the programme& programme organization	D
	As a result of the political coalition agreement in 2018, a programmatic approach was chosen to bundle projects in the renovation of the quay wall	D
Barriers	**Contract and Regulation-related**	
	Contract form	I
	Scope and/or requirement not clear or too rigid	I
	Procurement procedure	I
	Financial-related	
	Reduction of programme budget to halve of the initial budget	D& I
	Difficult to internalize benefit	I
	High innovation cost	I
	Collaboration and Cultural-related	
	The relationship between program organization and market parties are negatively influenced due to budget cuts	I
	Contractual procedure	I
	Technical-related	
	Implementation of innovation is difficult due to uncertainty and the adjustment of the design is therefore required	D& I
	Client-related	
	Based coalition agreement, the budget is reduced. Although the municipality also understands that a sufficient budget is required to realize the programme objectives	D& I
	Strick requirements and demand of internal stakeholders are costly, resulting in early budget depletion	D& I
	programme organization is shrunken which results in a reduction of organization capacity and influences the knowledge continuity	D
	Client organizational size/structure hinders the decision	I
	Conflict between goals and requirements	
	Market-related	
	Covid-19 crisis influences the price of materials and therefore influences the initial estimated price/km of renovation works	D
	Time-related	
	Long innovation trajectory and long design duration	I
Output	Innovation as a technology to renovate quay wall	D
	Intellectual property for the developed innovation	D
Outcome	Faster renovation of quay wall	D
	Less hindrance to surrounding	D
	Low cost	D
	Widely applicable to other quay wall renovation	D

4.2. Case Renovation Road Tunnels (RTR)

4.2.1. RTR document review

Enablers and barriers from documents

Enablers and barriers are identified in the RTR programme based on the project's documents, focusing on the perspective of TEC.
The following barriers are found:

- Although TEC has previously experienced working with DTT in tunnel projects, scaling it up to such a large extent is unprecedented and this is seen as a technical challenge. The Large-extend application in RTR can be described as the complete functionality of DTT [RTR3]. In addition, the utilization of BIM and DTT was also new for the municipality, therefore the programme organization [RTR3]. Lack of experience in technology from both parties became a big challenge in RTR.
- The variances among tunnels prove to be more substantial than initially anticipated, complicating the achievement of standardized solutions aimed by the programme organization [RTR7]
- As a result of the different technical complexity of the tunnels, adjustments must be made to the design and induced delay in delivery of design [RTR9]
- Postponing the execution of the third tunnel and the traffic center reduces the benefit of integrality and functionality of BIM and DTT because the assets are supposed to be related to each other [RTR7].

The following enablers to DTT development and implementation are also found in the documents:

- The development of DTT products and functionality is done and contracted at the programme level to ensure uniformity and integrality across projects [RTR3]. With this approach, the efficiency of DTT development is guaranteed, even though adjustments are still needed at the project level
- programme organization committed to the completion of the first two tunnels although the budget for RTR complete programme was retained by the political coalition (in Dutch: College van B&W) [RTR7]. This situation indicates a presence of leadership in the programme organization. However, although the third tunnel and traffic center projects are postponed, the programme organization demanded that the design for these two projects be completed.
- The delivery of DTT products is done partially by using Scrum methods which allows the stakeholders to give feedback on the products. Scrum consists of a feedback system, the so-called sprint, where the products are improved, and the quality is maintained within a short period of time [RTR3]. The required change to the functionality can be implemented in subsequent sprints. The basic functionality remains central to DTT while the extra functionality can be added after coordination with stakeholders to ensure the functions are quickly visible to them.
- There is a clear responsibility role between the contractors and the DTT specialist (as part of the design team) that works hand-in-hand to support and fulfill the stakeholders demands. Regular communication between the clients and contractors is maintained to ensure their satisfaction with the products [RTR3]
- Collaboration is central to the implementation of DTT and BIM. Formal reviews are conducted once the products are completed and ready for implementation. Through the feedback system, findings during the execution phase are reported to the integrated design team [RTP3]. Bi-weekly progress meetings and monthly update meetings are held to ensure the commitments of stakeholders are maintained. The concerns and progress of the implementation are discussed during the meeting by engaging related stakeholders, including the contractors. This is seen at the beginning of the collaboration agreement as well as during the implementation phase [RTP3, RPT4)]. Aside from the above-mentioned regular meetings, quarterly progress meeting is made with the programme team [RTR3].
- To overcome the technical challenge of DTT implementation, various tests were conducted to ensure the DTT system works. This included not only the individual products/functionality test but also the integration test, system test, and acceptance test which involved the clients and stakeholders [RTR3, RTR7].

- Once the contract of execution was awarded to the contractors, DTT developers, and contractors worked closely to establish the development of DTT in the individual tunnel. As mentioned earlier the contractors were contracted under an alliance agreement and early contractor involvement. It indicates that the collaboration form facilitates the collaboration between DTT developers and contractors.

Summary of document review RTR
RTR is a multi-year renovation tunnel project consisting of three tunnels and one traffic center, organized by the programmer organization formed by the Municipality of Amsterdam. The projects are executed consecutively. RTR has two main objectives. Firstly, it aims for a secure and accessible road tunnel by promptly adhering to tunnel regulations. Secondly, it seeks consistent operation, monitoring, and functionality, while also developing future-proof tunnel equipment to enhance tunnel safety and availability. To achieve the second objective, BIM and DTT innovations are utilized and designed at the programme level, where TEC is involved in the design team. The programmatic approach was chosen not only to achieve the aimed standardization and uniformity but also to accelerate the knowledge transfer from one project to another. Acceptance of the stakeholders is one of the important elements in the RTR programme, especially the tunnel management organization to whom the tunnels are handed over after the renovation works are completed. TEC is involved in RTT under a framework agreement to design and manage a strategic implementation of DTT. For the execution, contractors were contracted under an alliance agreement for the renovation of Tunnel 1, and a two-phase contract for Tunnel 2. The first phase of Tunnel 2 utilized an early contractor involvement to engage the contractor earlier in the design. These two types of collaboration facilitate the implementation of DTT in RTR and influence the collaboration between the client, TEC (as part of the design team), and contractors.

Some elements of innovation are also found and they are summarized in Table 4.4. A detailed analysis of the RTR and the innovation process can be found in Appendix F.2.

Table 4.4: Findings from document review RTR

Innovation elements	Descriptions
Drivers	Achieve uniformity and integrality of tunnel operation, including testing, and training of tunnel personnel
Inputs	programme budget Knowledge from previous projects using DTT Large volume of works (functionality of DTT) in renovation works
Enablers	**Contract and Regulation-related** Contract form facilitates the collaboration between clients and design teams using framework agreements and between clients, designers, and contractors using alliance and two-phase contracts. These collaborations form facilitate the development and implementation of innovation in programme
	Collaboration and Cultural-related Adoption of Scrum methods to stage the feedback from the users and enable early review. This facilitates the engagement of stakeholders in the programme and improves the quality of the delivered product Positive indication of collaboration is observed such as clear responsibility between different roles in the programme, regular communication between clients and companies in the form of bi-weekly, monthly, and quarterly meetings
	Technical-related To overcome technical challenges, various tests are conducted to ensure the functionality of innovations
	Client-related Clients vision to organize the renovation works using a programmatic approach helps the implementation of innovation at a large scale, therefore the efficiency of the innovation is also guaranteed Although the two last projects are postponed, the municipality committed to completing the first two projects and completing the design for all the projects
Barriers	**Technical-related** Although companies have prior experience with the technology, the implementation of innovation on a large scale in never been done The uniqueness of each tunnel complicates the achievement of standardization solutions, therefore adjustment to the design must be done
	Client-related As an influence of political decisions, projects within programme are postponed. This situation influences the aimed benefit of using DTT because the greatest benefit will be achieved if the assets planned are related to each other Client organizational size/structure hinders the decision
Output	Full functionality of DTT innovations in tunnel renovation
Outcome	Achieve uniformity and standardization in tunnel control and management

4.2.2. RTR Semi-structured interview

Barriers of innovation in RTR

Four major barriers are indicated in the RTP: Technical challenges, collaboration related to stakeholder's acceptance, Financial related to innovation cost, and client-related barriers.

- **Technical Challenge**
  Technical challenge is indicated by the interviewees as a major barrier during the development and implementation of DTT. While TEC has previous experience in implementing DTT in tunnel projects, scaling it up to such a large extent has not yet been done. Interviewee P1RTR mentioned "Another problem that we later ran into ourselves, is that we had technical challenges in that because it was new, had actually never done it before", Interviewee R2RTR added, "There were all kinds of technical challenges, but those were technical challenges that were eventually resolved". The technical challenges happened not only in the design but also in the executions. This is where the role of TEC is required to support the contractors in the implementation process, ensuring that DTT is effectively incorporated by the respective contractors [P1RTR]. Although the technical challenge is still seen as a barrier in the development and implementation of DTT in RTR, it is relatively easy to solve with the availability of various tools, as mentioned by interviewees R1RTR and R2RTR.

- **Collaboration and cultural-related**
  In addition to the technical challenges, the interviewees highlighted stakeholder acceptance as a significant barrier to the adoption of DTT innovation. The municipality, being a large organization with diverse (internal) stakeholders, plays a pivotal role in influencing the programme. These stakeholders hold their own perspectives on innovation, often favoring proven technologies over new ones. This was mentioned by P1RTR "..a large organization so lots of stakeholders all with their own needs, that makes that difficult". In addition, R1RTR mentioned "The biggest challenge, as far as I'm concerned, is mainly on the people side, and I find that with infrastructural works or people in engineering, people are often underexposed" and by R2RTR "There you get a kind of miscommunication and a kind of different expectations of what the technology could bring, and also a piece of resistance from people who have been used to doing the work for 30 years in a certain way and continue to do it that way". Within the programme, Tunnel organization is a dominant stakeholder who is also an end-user of the DTT. This stakeholder currently follows traditional methods for managing, controlling, and maintaining road tunnels. It is crucial to gain the acceptance of this stakeholder, as their support is essential not only for the successful implementation of DTT but also for its long-term continuity. Building their acceptance and trust in the benefits and value of DTT is vital for its effective integration into the stakeholder's operations and future practices [R1RTR, R2RTR, P1RTR].

- **Financial-related**
  According to the interviewees, the cost of innovation presents a barrier to the development and implementation of DTT. Implementing DTT requires a substantial investment, and in the case of RTR, the client bears the cost of this innovation. The high investment could become a source of resistance to the projects, as mentioned by R2RTR, therefore influencing the programme. Interviewee R1RTR also mentioned, "Generally, cost, in a word is often a barrier to innovation, because it's costs that you incur that you didn't incur before, so is very easy to say no to that". Despite the clear commitment from the client regarding DTT implementation, there is a need for a robust business case that justifies such a significant investment. R1RTR said, "Yes, with just a viable business case. That's saying, it costs an investment of x amount, but it yields so much". The client must carefully evaluate the potential benefits and value derived from DTT to justify making this substantial financial commitment.

- **Client-related**
  The acceptance of stakeholders plays a crucial role in the implementation of DTT, and it is influenced by the size and structure of the client's organization. To maximize the benefits of this innovation, it is essential for end-users to have a comprehensive understanding and vision of its potential, as mentioned by P1RTR. Engaging with a diverse range of internal stakeholders right from the initial stages of innovation development would have been highly beneficial. Such early engagement would have facilitated a smooth transition and fostered a shared understanding of the innovation's objectives and benefits among all stakeholders involved. For example, as mentioned by P1RTR " (Maintenance) wasn't part of the programme, but at the same time of course, it would have been better, if we could have talked to that organization in the front end because that transition to that would have been much easier". Furthermore, the interviewee highlights that the maturity of the client's organization plays a significant role in the successful implementation of innovation. This has been mentioned by R2RTR, "It largely depends on the people you are dealing with and the organization and the maturity of the organization". It is not only crucial to gain acceptance of the innovation but also to foster collaboration among different departments within the organization. This intra-departmental collaboration is essential for the effective integration and utilization of DTT throughout the client's organization.

Enablers to innovations in RTP
Eight enablers to innovation are identified in the RTP. The discussion below is organized based on the categorization: financial-related, contract and regulation-related, Collaboration and cultural-related, client-related, and knowledge exchange-related enablers.

- **Financial-related enablers**
  In RTP, two financial-related enablers play a significant role: a solid business case and an inno-

vation budget. These two enablers are closely interconnected. The presence of a solid business case is crucial for the successful implementation of DTT, as it demonstrates the clear benefits that arise when multiple projects are organized at the programme level, as said by interviewee R1RTR, R1RTR, and P1RTR. By grouping projects together, the high costs associated with development can be spread out, thereby mitigating the perception of high innovation costs as a barrier. Interviewee P1RTR mentioned "And it actually emerges that if you do it at the programme level, a large part of the development costs only needs to be paid once". R1RTR also added "It generated more (benefit) than it cost, so budget obviously is just a positive reference. If you look at the schedule, the tunnel opened 30% earlier than if you had done the traditional way of testing and designing". The interviewees R1RTR and P1RTR indicated that when there is a solid commitment from the client to implement innovation and there is a positive business case, there is always room for innovation, and the budget is made available for the implementation of innovation.

Innovation must be introduced at the early stage of the programme, in order to justify the business case. It has been mentioned by interviewee P1RTR "Fairly early in the programme that the budget was just available, which was also quite substantial". In addition, the budget availability as proposed, helps the smooth implementation. This has been said by R1RTR "We were very lucky that our client has very high ambition in terms of Digital Twin. For that, it was budgeted for and in the end, was convinced of it".

- **Contract and regulation**
  As indicated in the previous section, TEC is contracted under a framework agreement to provide advice and assist in the design of tunnel renovations. It is indicated by the interviewees that this contract form is suitable for the development and implementation of innovation because TEC works on behalf of the clients [R1RTR]. This provides room for changes and flexibility because TEC is part of clients' organizations. Within this contract form, TEC could work closer with the contractor for the implementation of innovation and this helps the implementation of DTT in the projects [R1RTR, R2RTR]. This has been mentioned by interviewee R1RTR "I think, we are really part of those client organizations. Their goals also become our goals " and interviewee R2RTR said, "That is the flexibility of this framework agreement, we performed tasks for the clients' side as well as the contractors' side and it was worked in this contract form.". The framework agreement, therefore, stimulates a long-term collaboration, as mentioned by R2RTR "It does help to have long-term cooperation with a consulting firm that recognizes the situation that can, therefore also apply learning effects within such projects".

  Similarly to the findings in the document review, the client's choice to utilize an alliance agreement with the contractors, has helped the close collaboration between clients, designer, and contractor. Interviewee R1RTR mentioned "So I think it was a good choice to take this on in alliance to ultimately ensure that we all look at what we want. Well maybe also necessary if you want to implement innovations, that you have to start thinking more like an alliance than the traditional principals-contractors". Interviewee R2RTR similarly said, "It was a lot more flexibility also in working with the contractors". The contract also helps to clarify the risk allocation for the implementation of innovation. In this case, because TEC is hired under the framework agreement, the biggest chunk of the risks falls on the client's side. However, consequences for failed advice are bared by the advisors, as mentioned by P1RTR.

- **Collaboration and cultural-related**
  Positive collaborative efforts and network configuration are two important enablers indicated by the interviewees. Aside from these two factors, trust and leadership are two additional enablers of DTT innovation. The implementation of DTT relies heavily on collaboration. Regular progress meetings are conducted regularly, to ensure that all stakeholders remain committed to their responsibilities. During these meetings, the concerns and progress of the implementation are discussed, involving relevant stakeholders, clients, and contractors. P1RTR indicated that there was a lot of flexibility and trust while working with the client and it gave a security to work on the projects. Between the partner companies in TEC and clients, there were a lot of discussions that resulted in solutions to problems, as mentioned by R1RTR and P1RTR. A positive collaboration is

not only seen between TEC and the municipality but also with the contractor. Once the contract for tunnel renovation is awarded to the contractor, TEC works closely with contractors to establish the development trajectory of DTT. The challenges faced during the implementation are discussed with the related parties. As said by interviewee P1RTR ”We discussed what we were up against. We even saw multiple options. What could we work on?”. Interviewee R1RTR also mentioned, ”I think we worked a lot with each other (with contractors) there to make that happen”.

The network configuration in TEC clearly has a positive impact on the development of DTT. RHDHV and Witteveen+Bos under the consortium TEC had early experiences with DTT. Together with Infranea, it bundles the knowledge and experience from the market that help further development and implementation on a larger scale. Interviewee P1RTR mentioned, ”That knowledge was not very large presently, so at this point, I could actually select at the beginning, from each company and partner, the best persons who did have that knowledge or were suitable, which is why I think we have a good team”. R1RTR also said ”In TEC context, then you have two big companies. If you combine all those forces, of course, there are more capacities people but also in terms of knowledge”. In addition, R2RTR added, ”In this case for the Digital twins specifically did indeed involve a subcontractor who helped in developing and also applying the Digital Twins, which is our party Infranea who are very involved in such developments”.

Leadership of the client is another element of collaboration that enables the development and implementation of DTT. As mentioned by R1RTR and R2RTR, the client in RTR has high ambition in relation to the management of road tunnels. The presence of leadership in programme organizations highly contributes to innovation. In combination with the strong business case, the leadership helps facilitate the realization of budget and collaboration. Interviewee R2RTR mentioned ”So it makes the topics discussable. When you’re dealing with a stakeholder, a client, in this case, leadership who actually supports it, that means you don’t have to justify every discussion about it again”. In addition, interviewees indicate that the presence of trust helps the collaboration and unity of the various parties involved in RTR. This is further related to the problem solution, where parties can discuss the problems with each other and find an agreeable solution, as mentioned by P1RTR and R2RTR.

- **Knowledge exchange enablers**
  The interviewees indicate that knowledge exchange with external TEC contributes to the development, implementation, and continuity of DTT. Especially arranging the development at the programme level, the effort to develop at this level paid off because the knowledge gained from bundling the design of multi-project can be used in the implementation of projects. The high standardization and uniformity of design at programme level eliminate the need to develop the project one by one, as mentioned by interviewee R1RTR. The design team was still required to work closely with the contractors that executed the renovations and was facilitated by the alliance contract chosen by the client. Knowledge exchange is therefore facilitated. Interviewees R1RTR and R2RTR added besides RTP, the expertise and insights acquired by TEC are highly valuable for the ongoing advancement and execution of DTT in other projects. Moreover, interviewee R2RTR mentioned this contributes to the overall knowledge enhancement of DTT in the market, which is further facilitated through a knowledge consortium such as COB.

Precondition to innovation in RTR
Drawing from the RTR case, there are four fundamental prerequisites for the development and implementation of innovations. The first requirement is having an adequate budget allocated for innovation development. The interviewees R1RTR, R2RTR, and P1RTR emphasized the significance of clients displaying strong commitment and possessing a clear vision and intention in driving innovation. It is crucial for this intention to be effectively translated into well-defined scopes and requirements, providing clear information to participants in the market. Additionally, establishing suitable contractual arrangements and partnering with appropriate allies is identified as another vital precondition highlighted during the interviews, as mentioned by P1RTR, R1RTR, and R2RTR. Lastly, involving capable partners is also noted as a prerequisite since the right partner plays a key role in realizing the client’s vision and intention [P1RTR, R1RTR, R3RTR]. Interviewee R1RTR mentioned, ”So I think here a mix of

contract form, a customer who clearly knows what he wants, we who have experience in that field, and can also provide the people and capacity". Interviewee P1RTR added, "If you have a very professional client that knows exactly what they want with that technology and how you want to achieve that and also can put that very well on paper".

Summary of interviews in RTR
Based on the interview, there are four pre-conditions for the successful development and implementation of innovations in programme: the availability of an adequate budget, strong commitment and vision from clients, a suitable contract, and availability of suitable and capable partners.
There are four barriers and eight enablers to innovations identified from the interview and they are categorized as a category in Section 2.4.1.

Table 4.5: Summary RTR interviewees

Barriers	Enablers
Collaboration and cultural-related - stakeholders' acceptance	Financial related - Financial solid business case
Technical related - technical challenges	Contract and regulation related - Contract form
Client related - client organization size/structure	Collaboration and cultural related - Collaborative effort positive
Financial related - innovation cost	Collaboration and cultural related - network configuration
	Client-related - Clear vision and ambition
	Collaboration and cultural related - Leadership
	Financial related - Financial Innovation budget
	Knowledge exchange related - External

4.2.3. Summary of RTR Case
The table below provides an overview of findings based on document review and semi-structured interviews for the RTR case.

Table 4.6: Summary RTR

Innovation elements	Descriptions	Source
Drivers	Achieve uniformity and integrality of tunnel operation, including testing, and training of tunnel personnel	D
Inputs	programme budget	D
	Knowledge from previous projects using DTT	
	Large volume of works (functionality of DTT) in renovation works	D
Preconditions	Adequate budget to innovations	I
	Strong commitment and vision to innovation from clients	I
	A suitable contract to facilitate collaboration	I
	Available partner/parties to collaborate that have knowledge (capabilities)	I
Enablers	**Contract and Regulation-related**	I
	Contract form facilitates the collaboration between clients and design teams using framework agreements and between clients, designers, and contractors using alliance and two-phase contracts. These collaborations form facilitate the development and implementation of innovation in programme	D& I
	Collaboration and Cultural-related	
	Adoption of Scrum methods to stage the feedback from the users and enable early review. This facilitates the engagement of stakeholders in the programme and improves the quality of the delivered product	D
	Positive indication of collaboration is observed such as clear responsibility between different roles in the programme, regular communication between clients and companies in the form of bi-weekly, monthly, and quarterly meetings	D & I
	network configuration	I
	Leadership from clients	I
	Technical-related	
	To overcome technical challenges, various tests are conducted to ensure the functionality of innovations	D
	Financial-related	
	A solid business case	I
	Availability of dedicated innovation budget	I
	Knowledge sharing-related	
	Knowledge sharing related to external	I
	Client-related	
	Clients vision to organize the renovation works using a programmatic approach helps the implementation of innovation at a large scale, therefore the efficiency of the innovation is also guaranteed	D & I
	Although the two last projects are postponed, the municipality committed to completing the first two projects and completing the design for all the projects	D
Barriers	**Financial-related**	
	High innovation cost	I
	Collaboration and Cultural-related	
	Stakeholders acceptance to innovation	I
	Technical-related	
	Although companies have prior experience with the technology, the implementation of innovation on a large scale in never been done	D& I
	The uniqueness of each tunnel complicates the achievement of standardization solutions, therefore adjustment to the design must be done	D
	Client-related	
	As an influence of political decisions, projects within programme are postponed. This situation influences the aimed benefit of using DTT because the greatest benefit will be achieved if the assets planned are related to each other	D
	Client organizational size/structure hinders the decision	I
Output	Full functionality of DTT innovations in tunnel renovation	D
Outcome	Achieve uniformity and standardization in tunnel control and management	D & I
	Faster opening of the tunnel due to efficient testing and verification process	I
	Higher quality of training for tunnel personnel and testing and verification compared to the previous traditional way	I

4.3. Case Steel Bridge Renovation (SBR)

4.3.1. SBR document review

Enablers and barriers from documents

Enablers and barriers are identified in the SBR programme based on the project's documents.
The following barriers are found:

- Although the HPC was proven to help reduce the fatigue on the bridge deck, the additional weight of the new layer influences the strength of the main supporting bridge construction. It required a further calculation of the design and tighter inspection which determined the adjustment/reinforcement needed on the structure. It became also known that the fatigue did not only appear on the bridge deck but also elsewhere in the structure. The learning on this project became an input to the repair method for the next phase of repair projects. In addition, not only technical adjustment is applied, but the execution method of the project is also adjusted to ensure minimum hindrance to the traffic and shipping [SBR3]
- Although the learning from the first phase was brought to the second, technical adjustment was continuously needed due to the characteristics of the bridges. The fatigue behavior and the initial situation on these bridges were unique per bridge [SBR3]
- Factor such as the location plays a role in the execution of the projects. Due to the location in the main road network, the preparation took some time to divert the traffic safely. Various stakeholders such as a municipality, bridge authority, and marine traffic, also influence the renovation project by demanding their wishes on the projects such as increasing capacity, higher bridge deck, and noise reduction. These factors increased the projects scope and complexity which influenced the budget of the renovation projects.
- Due to the criticality of execution, tight supervision was needed in the first phase by the MC as control at programme level. It was due to the contractors not being experienced in executing the work. As a result, a considerable amount of supervision was needed [SBR1]
- Even though MC was responsible for Project management, changes in the contract (such as scope) still required approval from RWS. The approval process slowed down the project management control which was in the hands of MC [SBR1].
- In relation to the point above, the function of the project manager and contract manager from RWS was combined into one function while these two functions shall be assigned to two persons. This resulted in a conflict of interest between one person's tasks, aside from overloaded tasks that one must carry. In complex renovation work, a combined function from the client side appeared to be challenging and slow down the decision-making process required from the clients' side [SBR1]
- There were no clear indications about the budget in the documents, however in the SBR1 document it was stated that selective reparation on the process could be executed due to a short budget from the client [SBR1]. This may also be related to the Phase 2 project where the scope of the projects was enlarged due to poor conditions of the bridge, change in regulation, and demanding requirements from the stakeholders [SBR1]. It contributed to the increase in cost that was not expected from the original estimation.

The following enablers are found:

- The bundling of the projects facilitated the learning from one phase to another phase and from project to project. This was made possible through a presentation/meeting where the three parties MC, client, and contractor project teams sit together and discuss the design or evaluate the projects together. This process enhances collaboration and cooperation among parties [SBR1]
- The renovation works were complex and required detailed testing and verification. The review and acceptance process required a large number of documents. A digital tool was developed in Phase 2 to reduce the workload and provide a reliable system. This helped the collaboration between involved parties [SBR1]
- In preparation for the tender for a new bridge, various disciplines such as technical managers, supervisors, and project managers, brought knowledge, learning, and perspective based on the previous renovation work in order to refine the requirement. This process improved the efficiency of the decision process [SBR1]

- Through meetings, risks, and measures were discussed and agreed upon between MC and contractors and these processes helped the controlling the risk in terms of quality and time [SBR1]. In addition to formal communication, informal communication between MC and contractors helped to bring a positive impact on collaboration [SBR1]. A construction reflection tool was also utilized in Phase 2 to enhance collaboration between parties focusing on the soft side of projects, such as attitude, behavior, communication, and conflict resolutions [SBR1]
- The presence of bonuses motivates companies. Through a systematic way of review per quarter including topics such as scheduling, communication, quality, preparation works, consultation, and audit score, companies were rewarded bonuses [SBR1].
- Knowledge gained from the lab testing pilot projects provides confidence that HPC could be a viable solution for a fatigue problem for steel bridges [SBR9]
- Client made a significant effort and investment in the development of HPC, starting from lab testing to pilot project applications with close collaboration with knowledge institutions, universities, and companies. This showed a clear mission and leadership of the client in HPC innovation [SBR3, SBR9]

Summary of document review SBR
SBR is a long-term programme, created by RWS in 2009 to organize the renovation of eight steel bridges (SBR) in the Netherlands. SBR has currently ongoing for 14 years and in the tendering process for the last bridge. SBR programme aims to renovate the steel bridges in the major road networks that were due for renovation. Based on the result of lab testing and pilot projects, HPC innovation was seen as a viable solution to extend the life of the bridges for another 30 years. In addition, due to the novelty nature of HPC, there was a need to organize the projects in groups in order to build the learning curve in designing and implementing HPC on the steel bridge decks. Although in practice, HPC was only applied in six bridges, the six bridges were interrelated and centrally coordinated by the Managing Contractor consisting of RHDHV, Arup, and Greiss. They were contracted under the MC contract to organize the SBR and were responsible for the design. Three contractors were contracted under a framework agreement that limited the competition for the work on eight bridges. However, to acquire the work, the contractors must submit a tender. Organizing SBR using a programmatic approach and executing the projects in consecutive ways enabled the escalation of a learning curve for clients, MC, and contractors. SBR is considered complex due to the uniqueness of each bridge. As a result, careful analysis in design and execution must be done. In addition, due to the strategic location of the bridges, stakeholders highly influence the projects therefore SBR. It added the complexity of the projects in combination with the budgets. Sharing knowledge was encouraged internally and external companies in the form of formal or informal meetings. Elements of innovation such as drivers, inputs, enablers, barriers, outputs, and innovation outcomes are found during the document review and therefore summarized in Table 4.7. A detailed analysis of the RTR and the innovation process can be found in Appendix F.3. In the next section, findings from the semi-structured interview are provided when more elements of innovations are found.

Table 4.7: Summary document review SBR

Innovation elements	Descriptions
Drivers	Application of HPC innovation on steel bridges deck to extend the bridge's life Building market parties' knowledge on HPC application
Inputs	Bundling series of steel bridges of renovation works Knowledge from pilot projects
Enablers	**Collaboration and Cultural-related** Some indications for a positive collaboration effort from various parties, such as frequent meetings, and informal discussions have enhanced collaboration Close collaboration between MC, client, and contractors. Effort was made to nurture trust, positive behavior, and communication, as well as define a conflict resolution, such as using Construction reflection tool
	Technical-related Complex testing and verification of the works were facilitated by a digital tool. The tool improved the efficiency of the process for all parties involved Knowledge gained from the pilot project provided confidence in an implementation in SBR projects Technical limit of the bridges has stopped the further implementation of HPC on steal bridges in the Netherlands
	Knowledge sharing-related The bundling of the projects facilitates the learning from one phase to another phase and from project to project by three parties: MC, client, and contractor project teams. Various brought knowledge, learning, and perspectives based on the previous renovation work to refine the requirements for the next projects
	Client-related Client made a significant effort and investment in the development of HPC, starting from lab testing to pilot project applications. It showed a clear mission and leadership of the client in HPC innovation
Barriers	**Financial-related** Due to scope enlargements, only selective reparations could be made, and it could influence the quality of the HPC. Further, the scope change became costly for the projects
	Collaboration and Cultural-related Due to the criticality of execution, tight supervision was needed, which contributed negatively to collaboration
	Technical-related Implementation of innovation was complex and required adjustment. This contributed to the uniqueness of every bridge and the bridges condition that was worse than expected
	Client-related Stakeholders influenced the projects heavily by enforcing requirements that were outside the scope of the projects Client still retains its control and influence on the decision related to a contract, this hindered the decision process in the projects Clients project structure was different from the companies'. The function of project manager and contract manager was assigned to one person which could result in a conflict of interest, task overload, and slow down the decision process
Output	HPC as a proven technology to extend the bridge life for another 30 years
Outcome	Less traffic hindrance in major road networks Less impact to the environment instead of building new bridge

4.3.2. SBR Semi-structured interview

Barriers to innovation to SBR

There are five barriers identified in SBR based on five interviews: knowledge exchange barrier with external parties, technical challenge, time barrier, contract and regulation related to contract form, and financial related to innovation cost. These barriers are going to be described in this section.

- **Knowledge exchange barrier**
  According to the interviewees, knowledge exchange with external parties poses a significant barrier to the adoption of HPC innovation. This challenge is particularly prominent among the contractors involved in the renovation projects. While the implementation of HPC innovation is coordinated by MC, the actual renovation works are carried out by three different combinations of contractors who are in constant competition with each other, as mentioned by interviewees R1SBR and C1SBR. This competitive environment hindered external knowledge exchange, as each party tends to safeguard its knowledge for its own advantage. Consequently, knowledge exchange primarily occurs internally between the MC combination and the client, and it is limited to the contractors involved. Overall, this hinders the overall development of HPC knowledge. Interviewee C1SBR indicated ”We were always in competition, so you don’t know where the knowledge stays, and then because we had new tenders after that, knowledge was shared, but at a high over level not really at the detail level” and it was agreed by C2SBR ”The knowledge sessions, which were conceived in the beginning, yield nothing because everyone kept their cards in front of their chest”. In addition, interviewee R1SBR mentioned ”With the contractors, it was noticed right away that HPC has big market value, so the knowledge exchange was very bad” and interviewee R3SBR also mentioned ”Knowledge sharing didn’t become very extensive in the end and that makes sense because there is also some competition. But knowledge has been shared.”

- **Technical Challenge**
  HPC implementation faces technical challenges, a barrier for both MC and contractors due to limited large-scale application experience. Designing the HPC layer required iterative calculations to ensure proper thickness without compromising the supporting structure, indicated by R1SBR and R2SBR. Interviewee C1SBR also added, ”Applying high-strength concrete is critical. It requires a lot of preconditions to get it done right”. Interviewee R1SBR indicated that although HPC has similarities to the application such as in airport landing strips, the contractors and MC did not have experience with HPC on a large-scale application. Furthermore, it is important to note that not only technical adjustments are made, but the execution method of the project is also modified to minimize disruptions to traffic and shipping. In the last phase of renovation, the technical limit of the bridge was reached and it ended the implementation of HPC on other orthotropic bridges’ renovation, not only in SBR but also in future renovation of similar bridges in the Netherlands, as mentioned by R1SBR and R3SBR.

  Interviewee R1SBR clarified that the selection of bridges in phase one was selected due to the technical urgency to repair those bridges quickly. But it was also the order of the bridges in SBR that was defined based on the increasing bridges’ complexity. ”The biggest comprehensive bridges were actually the first badge of 3, is mainly to learn for MC side, but also contractors side and the second batch is then really serious and that last one is Bridge 8. That should all come together because the impact is just really big”, quoted interviewee R1SBR. It is also noticeable that in the first phase, all the MC and the contractors were learning to improve the design and the technique from practice. The impact of the experience from the first phase could be seen in the second phase although there were additional challenges due to the increasing complexity of the bridges, as mentioned by R1SBR, R2SBR, and R3SBR. To add the technical complexity, interviewee R2SBR mentioned ”Because the bridges are so different in terms of length, size, and how they are constructed”. Interviewee R3SBR indicated ”The biggest hurdle with Bridge 7 was that we found out that in the end, it turned out HPC is not applicable there. HPC becomes a bit of a technical story”.

- **Time barrier**
  Time-related barrier in SBR is mainly related to the long duration of projects that are now running for around 14 years. It has been mentioned by interviewee R1SBR and also interviewee C1SBR.

C1SBR mentioned, ”The realization of eight bridges in the HPC Framework Contract took much longer in time than originally intended” and it was agreed by interviewee C2SBR ”We’ve only done two bridges in 10 years. That then is not a programmematic approach, that is not a multi-project”. Furthermore, the long-duration projects influence the collaboration with the client and contractors, therefore the quality of the projects and innovation. Interviewee R1RTR mentioned, ”It would have had to do with the long duration projects. Of course it always helps the shorter something does, the more attention you have and the more you can hold attention that will always help” and added, ”If you don’t continuously think that innovation always has been a driving force behind it, then at some point the driving force falls very quickly”.

- **Contract and regulation-related barrier**
  Although the interviewees agreed that a framework contract helps to facilitate innovations in SBR, which positioned the companies in less competition, the presence of a mini-tender within the framework contract hindered the innovations. C1SBR indicated ”It is limited because you are still in competition. For Cargo projects, our companies had been awarded eight bridges at one time. And, over there it was much easier to spend money on innovation because you could recoup that on 8 bridges and able to invest more heavily in people, methods, machines in developments”. C2SBR also added that high costs were incurred as a result of the occurrence of mini-tender and due to the adjustment of requirements, the project became a usual DC contract where it did not act as an incentive for innovations.

- **Financial-related barrier**
  High innovation cost is identified by the interviewees as a barrier to implementing HPC in the bridge. The cost of HPC is relatively high for renovation work and sometimes it is cheaper to build a new bridge. The interviewees C1SBR also add, if the high cost is spread out the life-cycle of the bridge, it is cheaper than building a new bridge. R1SBR added, ”Sometimes new construction was cheaper, but still opted for HPC because, for example, it would cause much less disruption or to continue to encourage the development of high-strength concrete.”. However, as indicated by C2SBR, within the projects only incremental innovation could be applied because it cost less and it matched with the company’s innovation budget which generally was not a lot in comparison with the profit margin.

Enablers to innovation to SBR
There are seven enablers to innovation identified from the SBR case study. They can be further categorized into contract and regulation enablers, knowledge exchange enablers, and collaboration enablers.

- **Contract and regulation-related**
  Contract forms were indicated by interviews as enablers of innovation. As indicated earlier in the document review, two types of contracts were used in SBR which were framework contracts and MC contracts. The interviewees R1SBR and C1SBR mentioned that the framework contract is a suitable contract form to facilitate the implementation of HPC innovation. C1SBR and C2SBR mentioned that limited competition could stimulate and facilitate innovations. However, it was also argued that the tender inside the framework contract will bring a negative impact, as has been elaborated in the barrier section. With the framework contract, the competition is much less and that allows the market party to contribute to the development of innovation, and development techniques, make investments in machinery, and spread the cost to more projects, as said by interviewee C1SBR.

  In relation to the MC contract, R3SBR indicated that it helped in the further implementation of HPC because the responsibility of the design came at the programme’s level. The investment that was made, not just financial but also knowledge, was applied to eight bridges. In the end, the effort would be paid off. In the MC context, it was not only the technical knowledge gained but also the project organizing and contractual knowledge. Interviewee R2SBR added, ”Deploying a programme in this way to motivate innovation is always good because if you roll out something that incorporates learning, you do get better and better solutions and innovative things occur”. R1RTR indicated that in a suitable contract such as a framework agreement and MC, a sufficient

number of projects must be included to be able to see the intended learning effect. This eventually to efficiency.

- **Knowledge exchange-related**
  Although knowledge exchange external was recognized as a barrier, the interviewees indicate that knowledge exchange both internal and external are major enabler in the implementation of HPC. Internally between MC partners, knowledge is continuously shared to improve the design of the next bridges. This knowledge is shared as well with the specialist from RWS as the client, as mentioned by R1SBR, R2SBR, and R3SBR. Interviewee R1RTR indicated ”Of course what we did within the MC is from every time we want to start to work with the new bridge, we went and collected the learning experiences from the earlier bridge”. Interviewee R2RTR added, ”So basically if you do such programme, you can also take the learning process and the knowledge that you gained very actively in the process, and implement it in the next projects”. Due to the bundling of projects, working on such projects becomes more interesting because the continuous knowledge gained can be directly applied to another project. If the team remains the same, it is nice to have a team that has a solid understanding of the projects and innovations, builds a learning curve, and works together, such as those mentioned by R1RTR and R2RTR.

  Within the contractors' combination, which typically comprises three or four contractors, there was active knowledge exchange to enhance the implementation of HPC. The internal exchange of knowledge plays a crucial role in improving the utilization of HPC. Interviewee C1SBR mentioned, ”We did evaluate all phases internally very well and have been constantly improving and adjusting the procedure”. As a positive impact of gaining knowledge in innovation, in the SBR context, although HPC is proven not applicable in the Netherlands, the contractors had gained valuable knowledge on certain innovations that enable them to enter the market outside the country, as mentioned by R1SBR, C1SBR, and C2SBR. While knowledge exchange among external contractor combinations is limited, evaluations with the MC were still conducted to enhance the implementation of HPC in future projects. This has been mentioned by interviewees R2SBR, C1SBR, and C2SBR. The knowledge sharing from contractors to MC was part of the contractual agreement and this was done in a formal meeting, as mentioned by interviewees R1SBR and R3SBR.

- **Collaboration and cultural-related**
  There are three factors related to collaboration that enable the development and implementation of innovation: positive collaboration effort, network configuration, and the presence of leadership. Positive collaboration is indicated as an enabler of development and implementation innovation in SBR. It was indicated by interviewee C1SBR, that clients had active roles in the execution, such as issuing the permits and managing surrounding traffic. Interviewees R2SBR and R3SBR also indicated that working together as a team with clients in one place has expedited the knowledge exchange formally and informally. Within the MC partners, a positive collaboration was indicated by the clear responsibility of each party and the knowledge and capabilities of each partner complement each other, as mentioned by R2SBR and R2SBR. An example of positive collaboration between MC and contractors was mentioned by R2SBR ”You work together with the contractor to get the best solution. You can't lay down an unrealistic schedule for the contractor. It has to be doable”. Interviewee R3SBR mentioned, ”Our technical team in close cooperation with the technical manager of the client and their steel bridge specialists, brainstorming and looking for solutions with each other”.

  The influence of networks is recognized as a facilitator for the implementation of HPC. The interviewees acknowledge that collaborating with a trusted partner from their network has a positive impact on their collaboration and, consequently, on the successful implementation of the innovation. This is one of the reasons why RHDHV formed a consortium with Arup and Greiss, as mentioned by R1SBR. The contractors also consider this factor when selecting their partner combinations, as they recognize the benefits of working with known partners from their network, as mentioned by C1SBR. In addition, interviewee C1SBR mentioned, ”And then when they bring up innovations, it's easier to develop something together with a trusted partner.” Interviewees C1SBR,

C2SBR, R1RTR, and R2RTR mentioned that collaborating with familiar partners offers valuable advantages during the implementation of innovations such as having effective problem-solving, nurturing trust, and facilitating seamless knowledge exchange among the project stakeholders.

Interviewees R2SBR and R3SBR mentioned that leadership from the client played an important role in the development of HPC. ”It’s good that they didn’t develop it all on their own, but then sought out market parties, with us as engineering firms and contractors to really develop it and make it more widely applicable”, said interviewee R3SBR. Developing and implementing innovations need a strong commitment, and vision from the client, as well as different types of management, as mentioned by C2SBR.

Precondition to innovation in SBR
The interviewees R1SBR, R2SBR, R3SBR, and C1SBR indicated that commitment and intention from clients is an important precondition for the development and implementation of innovation. Innovation needs clients that think outside of the box. The second factor is the availability of a dedicated budget to innovate because innovation requires investment. Interviewees R1SBR, R2SBR, and C2SBR indicated that problems are relatively solvable if innovations are sufficiently budgeted because they act as a means to reach the desired benefits from innovations. Furthermore, sufficient time is needed because a trial and error process will be part of innovation development. In addition, development and implementation innovations in programme should consider factors such as a sufficient number of projects, the size of the projects, the order of projects, and locations, to be able to see the learning effect, improvement between projects, desired output of innovations such as efficiency and effectiveness, that eventually help to achieve programme benefits, as indicated by R1SBR, R3SBR, and C1SBR. R1SBR mentioned, ”It’s just much better to issue batches of bridges or tunnels or whatever with the same problems so that you as a party can better anticipate them, so you can develop more knowledge, but also with your staffing can be better organized”.

Summary of interviews in SBR
As a result of the interviews, three pre-conditions for the successful development and implementation of innovations in programme are found: client commitment and intention to innovations, availability of budget, and last factor number of projects to be bundled based on the criteria such as size, order of projects, and locations of assets. There are five barriers and six enablers identified from the interview and summarized in the table below.

Table 4.8: Summary SBR interviewees

Barriers	Enablers
Knowledge exchange related - External	Contract and regulation enablers - Contract form
Technical related - technical challenges	Knowledge exchange enablers - External
Time barrier	Knowledge exchange enablers - Internal
Contract and regulation related - Contract form	Collaboration and cultural related - Collaborative effort positive
Financial related - innovation cost	Collaboration and cultural related enablers - network configuration
	Collaboration and cultural related enablers - Leadership

4.3.3. Summary of findings in SBR
The table below provides an overview of findings based on document review and semi-structured interviews for the SBR case.

Table 4.9: Summary SBR

Innovation elements	Descriptions	Source
Drivers	Application of HPC innovation on steel bridges deck to extend the bridge's life	D
	Building market parties' knowledge on HPC application	D
Inputs	Bundling series of steel bridges of renovation works	D
	Knowledge from pilot projects	D
Preconditions	Commitment and intention from clients	I
	Dedicated budget to facilitate innovations	I
	Sufficient time	I
	a sufficient number of projects, the size of the projects, the order of projects, and locations, to be able to see the learning effect, and improvement between project	I
Enablers	**Contract and Regulation-related**	I
	Contract form such as framework agreement helps the development of innovation	I
	Collaboration and Cultural-related	
	Some indications for a positive collaboration effort from various parties, such as frequent meetings, and informal discussions have enhanced collaboration	D & I
	Close collaboration between MC, client, and contractors. An effort was made to nurture trust, positive behavior, and communication, as well as define a conflict resolution, such as using Construction reflection tool	D
	network configuration facilitates collaboration, due to the presence of trust	I
	Leadership from the clients highly influence the development of innovations	I
	Technical-related	
	Complex testing and verification of the works were facilitated by a digital tool. The tool improved the efficiency of the process for all parties involved	D
	Knowledge gained from the pilot project provided confidence in an implementation in SBR projects	D
	Knowledge sharing-related	
	The bundling of the projects facilitates the learning from one phase to another phase and from project to project by three parties: MC, client, and contractor project teams. Various brought knowledge, learning, and perspectives based on the previous renovation work to refine the requirements for the next projects	D & I
	Knowledge exchange internal companies (combinations)	I
	Client-related	
	Client made a significant effort and investment in the development of HPC, starting from lab testing to pilot project applications. It showed a clear mission and leadership of the client in HPC innovation	D & I
Barriers	**Financial-related**	
	Due to scope enlargements, only selective reparations could be made, and it could influence the quality of the HPC. Further, the scope change became costly for the projects	D
	High cost of innovation	I
	Contract and Regulation-related	
	Contract form is a barrier when competition still requires/presence during the development of innovation	I
	Collaboration and Cultural-related	
	Due to the criticality of execution, tight supervision was needed, which contributed negatively to collaboration	D
	Technical-related	
	Implementation of innovation was complex and required adjustment. This contributed to the uniqueness of every bridge and the bridges condition that was worse than expected	D& I
	Client-related	
	Stakeholders influenced the projects heavily by enforcing requirements that were outside the scope of the projects	D
	Client still retains its control and influence on the decision related to a contract, this hindered the decision process in the projects	D
	Clients project structure was different from the companies'. The function of project manager and contract manager was assigned to one person which could result in a conflict of interest, task overload, and slow down the decision process	D& I
	Knowledge exchange-related	
	Knowledge exchange with external	I
	Time-related	
	Contract duration was too long, therefore hard to maintain relations. Time is also indicated as a barrier when only a few works were acquired during a long period of time	I
Output	HPC as a proven technology to extend the bridge life for another 30 years	D
Outcome	Less traffic hindrance in major road networks	D
	Less impact to the environment instead of building new bridge	D

4.4. Comparison of innovation process between case studies

Findings from three case studies have been explained in the previous section. This section focuses on the comparison between three cases which includes the similarities and differences. The analysis of this section will help to answer SRQ4.

4.4.1. Drivers, inputs, and preconditions

Three case studies are organized by the government organization and the programmes are driven by compliance with safety regulations. It indicates similarity in the primary focus of the three programmes which is to renovate the infrastructure assets in the Netherlands. To understand the innovation process, the drivers, inputs, and preconditions to innovations in three case studies are compared below and the overview can be seen in Table 4.10.

Drivers

The programme main goals are driven by compliance to provide safe infrastructures to the users. On the other hand, the secondary goals of these programmes vary, either to create value for the programme or to help achieve the main objectives. Innovations in infrastructure programme are driven by motivations to achieve the program objectives, such as seen in three cases. In QWR, the main driver for innovations is to expedite the renovation works with minimum hindrance, as quickly as possible, at low cost and the solutions can be widely applicable. Innovations are developed and implemented in the renovation of road tunnels to achieve the desired uniformity and standardization in tunnel control. In SBR innovations are needed to extend the steel bridge life. Although the motivation to utilize innovations in these programmes is unique per case they are aimed at achieving the programme main objective.

Inputs

There are two similarities of innovation inputs in these programmes. First, the availability of a budget is indicated as an important input of innovation. Depending on how the innovations are organized, the budget can be a separate or part of programme s/projects budget. As an example in QWR, IPQ was created by the municipality as a dedicated project to develop and implement innovations, where a dedicated budget was allocated to facilitate the development of innovations. While in RTR and SBR, innovations were developed at the programme level, therefore the budget was embedded as part of the design. The budget for the implementation of innovations was part of the project's budget. The second major similarity in innovations' inputs is the volume of works or projects to be bundled, as was indicated in three cases. This is because the development plan of innovations will depend on the certainty and sufficient volume of work which is further can be related to the amount of capital investment and human resources. In relation to this point, the availability of prior knowledge of innovations is seen as important in RTR and SBR. However, it is highly influenced based on the TRL level of the innovations, where the TRL level in both cases is around 6-7. In the QWR case, prior knowledge was not indicated as an input because the innovation was developed from a very low-level TRL (level 1-3 during the procurement phase).

Preconditions

From three case studies, one similarity of preconditions to innovation is found. A factor related to the budget and financial capability of companies or organizations is indicated in three case studies. This is because innovations need a budget for development and implementation and companies or organizations must be able to support the investment in programmes/projects. There is also a similarity that is found only in two cases. In the RTR and SBR, it was indicated that strong commitment and vision for innovations are needed. When the intention to develop and implement innovation is present, it has a positive influence on the input of innovations such as commitment to budget and other resources. In QWR, the trustworthiness of clients and partners is seen as an important factor. Client vision, commitment, and trustworthiness can be related to the culture and motivations for innovations.

There are also differences per case in innovation preconditions. For example in RTR, the availability of partners who own knowledge and capability to collaborate serves as a precondition to innovations The reason is even though financial resources are available but lack knowledge and capability from the market, innovations can not excel in projects/programme. The other factor is related to the contract,

where a clearly defined contract defines the development and implementation of innovations in projects. This factor is closely related to the type of contract used in the case study, where certainty is needed by market parties to develop innovations.

Table 4.10: Comparison of drivers, inputs, and preconditions

Cases	QWR	RTR	SBR
Drivers	Expedite the renovation of quay walls with minimum hindrance, short lead time, solutions that are widely applicable, and low cost	Achieve uniformity and integrality of tunnel operation, including testing, and training of tunnel personnel	Extend the steel bridge life by applying HPC on bridges deck, Build market parties knowledge on HPC application
Inputs	Dedicated budget for innovation is available through IP as part of programme budget	Innovation budget is part of programme budget and individual project	Volume of renovation works
	Large volume of renovation works	Knowledge from previous projects using DTT	Knowledge of innovation from pilot projects
		Large volume of works (functionality of DTT) in programme level and projects level	
Preconditions	Preconditions Financial capabilities of companies/organizations	Strong commitment and vision to innovation from clients	Budget availability
	Clearly defined contract	Adequate budget to innovations	Commitment and intention to innovation from client
		Availability of partners/parties with knowledge and capability to collaborate	A number of projects to be bundled, based on criteria such as the size, order projects, and locations
		A suitable contract to facilitate collaboration	

4.4.2. Enablers to innovations

From three case studies, enablers per category are found, and their similarities and differences are discussed one by one as follows.

Contract and regulation related

A contract form is seen as a major factor in the development of innovation in three cases because of the clear risk-sharing and responsibility of each party. In addition, the contract promotes a long-term collaboration between clients and market participants. This is essentially needed because innovation involves an iterative process of refinement and improvement and this process requires time. In relation to a long-term collaboration that is needed for innovation, time duration determines a return on investment for innovation.

As seen in Table 4.11, the contract form used per case varies, depending on the TRL level of innovations. In QWR, a partnership agreement is used and differentiated into two phases. The development phase utilized a development agreement and only if the pilot succeeds, a framework contract will be awarded to the market parties. In the RTR case, RHDHV was contracted under a framework agreement for the design at the programme level. It is worth noting as well that in the RTR, the client entered an alliance agreement with the contractors to execute the renovation work. In the SBR, RHDHV was contracted under the MC contract and contractors were working under a framework agreement for the execution phase. The difference between the three cases is the TRL level of innovation, where in QWR innovation is developed from TRL 1 until 9, while in RTR and SBR, the innovations are already at higher TRL level.

Table 4.11: Comparison of contract form

QWR	RTR	SBR
Partnership agreement includes Development framework for the development phase, Framework agreement for the commercialization phase	Framework agreement	Managing contractor contract for MC, Framework agreement with mini-tender for the execution phase (for the contractors)
TRL level innovation from 1-9	TRL level innovation from 7-8	TRL level innovation from 7-8

Technical Challenge related
Drawing insights from the case studies, it was observed that in three cases, ongoing technical refinements and a range of tests and validations played a pivotal role in mitigating innovation-related risks. For example, in the case of QWR, technical adjustments were carried out in distinct phases, as depicted in Figure F.3. At the conclusion of each phase, rigorous testing and verification procedures were undertaken. Likewise, in the cases of RTR and SBR, specialized (digital) tools were employed for testing and validation, enhancing the efficiency of the process.

Collaboration and cultural related
Two similarities are found in three cases. First is a positive collaboration effort. As an example, meetings were utilized frequently and involved various parties as a means for discussion and problem resolution. In addition, transparency, open communication, and trust are indicated as factors that occurred in QWR, RTR, and SBR. Informal communication is indicated in SBR as a factor that helped the collaboration between MC and contractors. Another similarity that contributes to the development of innovations is the influence of company networks. According to the interviewees, collaborating with established partners plays a crucial role in facilitating the innovation process. By working with reputable parties within their network, companies can effectively address challenges encountered during innovation endeavors. A positive collaboration promotes the exchange of knowledge, joint research and development initiatives, resource sharing, and access to complementary capabilities, all of which expedite the innovation process. Moreover, companies seek out partners to bridge any knowledge gaps that may exist. This is particularly valuable when specialized skills are required. For instance, in the case of QWR, it was evident that securing the right partner was essential for successfully developing innovations and entering new markets. By establishing a strong network with reliable and esteemed partners, the perceived value and dependability of a company's innovations are heightened. Additionally, reliable partners are crucial in sharing the risks associated with innovation.

The differences between the three cases are also found, that are closely related to the case-specific. For example, in QWR, there is no competition among the three market combinations in IPQ, they can work hand-in-hand to think about solutions that could benefit them together. Another example, the (plan) is to create an innovation platform that facilitates a shared hub for transferring personnel and storing materials. In the SBR case, the contractors were in the competition as a result of the mini-tender, which resulted in a lack of collaboration. Another difference is in RTR and SBR, clients possess strong commitment, vision, and leadership are seen as major factors that help the successful implementation of innovations. The innovations are supported by a robust business case, placing innovation development and implementation in a strong position within the programme. In RTR and SBRR, the presence of a solid business case, a clear vision, and ambition from the client, along with strong leadership, are distinctive enablers. In addition, the innovations in these two cases were being developed or emphasized at the programme level instead of the project level. The difference with QWR is three market combinations are working to create three distinguished innovations.

Table 4.12: Comparison of collaboration and cultural related enablers

QWR	RTR	SBR
Indications of positive collaboration effort: utilizing meetings to facilitate communication, the presence of transparency, open communication between clients and market parties, and programme organization involvement to facilitate the knowledge exchange	Indications of positive collaboration effort: clearly defined responsibility between different roles in the programme /projects, utilizing meetings to facilitate communication and open communication, the presence of flexibility and trust, and active engagement with stakeholders	Indications of positive collaboration effort: conducting frequent meetings, utilizing informal discussion to enhance collaboration between MC, client, and contractors. An effort was made to nurture trust, positive behavior, and communication, as well as define a conflict resolution, such as using the Construction reflection tool
The initiative arose from three IPQ market combinations to utilize an innovation platform that facilitates cooperation (still plan)	Network configuration influences collaboration because reliable partners were selected based on experience. The combined knowledge and capacities of companies support the development of innovations	Network configuration facilitates collaboration, due to the presence of trust gained from experience
As a result of positive past experiences, partners were selected (from a network) which helped to nurture trust and good collaboration	A strong commitment from a client was demonstrated through leadership, indicated by the commitment to budget and business case	Leadership from the clients expedited the innovation process and enforce its wide application

Knowledge exchange related

The exchange of knowledge with external parties is identified as a common facilitator across three cases. In all three cases, knowledge exchange with clients emerges as a significant factor in driving innovation development. This is because client input and support are vital for innovation, and a certain level of adaptability is required during the development process. Consequently, knowledge exchange encompasses not only the transfer of technical expertise but also process knowledge. Moreover, in the context of SBR and RTR, knowledge exchange with external companies or other relevant parties is crucial. This is because different responsibilities exist between innovation development in the design phase and innovation implementation during execution. In close connection to the influence of networks, seeking trustworthy partners plays a key role in facilitating knowledge exchange and bridging any knowledge gaps between partners. This is seen in all three cases where partners are chosen based on their capabilities. Furthermore, knowledge exchange is also closely related to the contract form. As indicated by the interviewees the contract facilitates collaboration with the external parties (outside the combination with partners) and when the collaboration is permitted, the knowledge exchange is directly stimulated with these parties.

Table 4.13: Comparison of knowledge exchange related enablers

QWR	RTR	SBR
Knowledge exchange related to external parties is facilitated by programme organizations such as a dedicated programme function that actively contributes to the development of innovations	Knowledge exchange with external parties contributes to the innovation, especially in the implementation phase where close collaboration with contractors takes place. The knowledge exchange also happens within the communities of experts in the market, which enriches the knowledge of companies	Knowledge exchange with external parties is stimulated and facilitated through the bundling of the projects. The learning from one phase to another phase and from project to project by three parties: MC, client, and contractor project teams are facilitated. Various parties brought knowledge, learning, and perspectives based on the previous renovation work to refine the requirements for the next projects
Knowledge exchange related to internal parties is facilitated through trust, positive attitudes, and past experiences. Knowledge exchange from these parties is beneficial and complements each other		

Client related enablers
From three cases, there is one distinctive similarity in relation to the clients. In RTR and SBR, client vision and commitment to use innovation in a programmatic approach are obvious. This was done through providing continuous support in relation to the development and implementation of innovation, as indicated in documents and interviews. As an example, although there was a budget cut from the municipality, in the RTR case, the programme organization strove to complete at least the second tunnel renovation and design at the programme level. Similarly, in the SBR case, the vision to implement innovation came from the client and became the reason for programme creation. In QWR, it was found during the document review that the client, in this case, the municipality, has intended to support the programme, but this point was not indicated during the interviews. However, in QWR, the decision for programme creation was a result of a political decision in 2018, indicating that the client has a strong commitment to programme.

Table 4.14: Comparison of client-related enablers

QWR	RTR	SBR
Continuous commitment indicated by the clients organization to support the programme organization	Clients vision and commitment to organize the renovation works using a programmatic approach helps the implementation of innovation at a large scale, therefore the desired efficiency as the impact of the innovation is also guaranteed	Client made a significant effort and investment in the development of HPC, starting from lab testing to pilot projects application. It showed a clear mission and leadership of the client in HPC innovation
Political influence led to a decision to programme creation to expedite the renovation works		

Financial related enablers
From the three cases, only the SBR case indicates, based on the interview, that a solid business case and availability of a dedicated budget enables the development and implementation of innovations. In other cases, these two points were found as well but not a majority of answers from the interviewees.

4.4.3. Barriers to innovations
There are some major differences in the barriers found in the three cases. First, in QWR, the combination Koningsgracht works to develop and execute the renovation works in QWR while in RTR and SBR, the engineering companies have an advisory and designer role. Albeit the difference, it allows them to collaborate closely with the clients. The different roles, partially explain why QWR encounters more barriers compared to RTR and SBR. Second, the degree of innovation in the last two cases is relatively high TRL in comparison with the IPQ. This represents the maturity of innovations in the multi-projects. Innovation in QWR still needs to be further developed and has a long development trajectory before it reaches the desired efficiency and effectiveness while in RTR and SBR, prior experience and pilot projects help the development and implementation of innovation in multi-projects. Third, the innovation in QWR is developed at the project level while RTR and SBR innovations are developed at programme's level.

Contract and regulation related
In QWR and SBR, a barrier related to contract form is found. When examining the specific barriers encountered by QWR, two primary sources of obstacles emerge. The first pertains to contracts and procedures. The IP, introduced by the European Union in 2014, is a unique form of collaboration that has been infrequently utilized by public commissioners. The case of the IPQ is the first instance where the municipality of Amsterdam has employed this contract format. Engaging in this IP necessitates a different approach to project organization, demanding collaboration among various internal stakeholders within the municipality. These stakeholders may have divergent requirements that could conflict with one another, as well as with the goals of the programme. Consequently, this can impede innovation development as innovations often require more flexibility than the prescribed requirements allow. Furthermore, in relation to requirements, it would be beneficial for innovation if clients had clear functional

requirements rather than being bound by rigid technical specifications. Clear functional requirements would provide market participants with the opportunity to develop innovative solutions. Additionally, the procurement procedures appear to pose barriers to the innovation process. Limited contact and unclear requirements hinder the development of innovation within QWR, particularly during the tender phase.

Table 4.15: Comparison of contract and regulation related barrier

QWR	RTR	SBR
Focus on contract details like IP, including risk-sharing, predictability, and Intellectual Property rights		The contract form such as the framework agreement is a barrier when competition still requires/is present during the development of innovation
Unclear or rigid requirements hindered innovation during the crucial procurement phase and hindered the needed creativity		
Regarding the above barrier, limited client interaction during procurement led to necessary assumptions		

Collaboration and cultural related

Three cases exhibit distinct collaboration and culture-related barriers, as seen in Table 4.16. In QWR, the programme budget cut became a source of collaboration issues as indicated in the document review and interviews. This is because innovation is developed in the programme from the low TRL level and at the project's level. In RTR, stakeholder acceptance, from the client's organization, hinders innovation due to resistance to change.

Table 4.16: Collaboration and cultural related barrier

QWR	RTR	SBR
The relationship between program organization and market parties are negatively influenced by budget cut	Stakeholders' perspectives influence acceptance, often favoring tradition over long-term innovation benefits	Due to the criticality of execution, tight supervision was needed, which contributed negatively to collaboration
Contractual procedures hinder collaboration, especially in the early phase		

Technical related

The analysis of three case studies highlights that technical challenges remain a barrier to innovation regardless of the innovations' level. In QWR, RTR, and SBR projects, actors encountered varying degrees of technical challenges. RTR and SBR successfully implemented innovations in multi-projects, while QWR is still in the pilot phase. It is likely that technical challenges in QWR will diminish as technology uncertainty decreases over time. These challenges stem from risks, assets uniqueness, and increasing complexity, making large-scale implementation difficult despite prior knowledge and experience.

Table 4.17: Technical related barrier

QWR	RTR	SBR
Innovation implementation complexity arose from the unique characteristics of each bridge and their worse than expected conditions	Although companies have prior experience with the technology, implementation of innovation on a large scale is never being done	Implementation of innovation was complex due to the uniqueness of every bridge and conditions that were worse than expected
	The uniqueness of each tunnel complicates the achievement of standardization solutions	

Knowledge exchange barrier
Similar to the market barrier, the knowledge exchange barrier is only found in the SBR case. The knowledge exchange barrier with external parties was only experienced by the contractors. The reason is the presence of mini-tenders created competition between contractors, while in QWR and RTR the competition between companies was removed in the innovation process.

Client related
There is a clear resemblance concerning the client-related obstacle between the two client cases, namely QWR and RTR, both of which are managed by the same clients. In contrast, SBR is initiated by RWS. Despite the programme organizations having authority over the programme, political decisions wield influence over the budget of the QWR and RTR programme. This influence leads to postponing projects and other challenges, as elaborated upon in the section addressing other barrier categories. Among the three cases, QWR encounters greater difficulties, partially due to the fact that innovation within IPQ is structured at the project level, whereas innovations within RTR and SBR are structured at the programme level. The impacts of this structural difference are evident in decision-making processes, notably manifested in QWR's slower decision-making due to the client's large organizational size. The spatial separation of the project from high-level decision-makers contributes to a greater impact of internal stakeholders on QWR, in comparison to the other cases.

However, in RTR, similarities also exist with challenges regarding collaboration and internal stakeholders found in the QWR. In a sizable organization, a larger number of internal stakeholders wield influence over the programme, as well as the conception and execution of innovative endeavors within it. These stakeholders might possess vested interests and are accustomed to proven methods that have been in use for an extended period. Introducing innovation necessitates a distinct approach and the potential to enhance existing methodologies to realize programme advantages. This aligns with the QWR scenario, where both programmes stem from the same client organization and are closely tied to its organizational structure. In the context of QWR, conflicting and expensive demands from internal stakeholders lead to premature budget exhaustion. In SBR, two additional barriers associated with the client emerge. The initial barrier involves the client's continued authority in projects, particularly pertaining to contractual matters, resulting in obstructions to the project's decision-making process. The second barrier pertains to disparities between the project organization structure on the client's end and that of the companies, as evident from the documents review. These two barriers are absent in the scenarios of QWR and RTR, suggesting a potential connection to the unique organizational structure of this particular client.

Table 4.18: Client related barrier

QWR	RTR	SBR
programme budget is influenced by political decision	As an influence of political decision, projects within programme are postponed. This situation influences the aimed benefit of using DTT because the greatest benefit will be achieved if the assets planned are related to each other	Stakeholders influenced the projects heavily by enforcing requirements that were outside the scope of the projects
Strick requirements and demand of internal stakeholders are costly, resulting in early budget depletion		The Client still retains its control and influence on the decision related to the contract, this hindered the decision process in the projects
Re-organization of programme organization results in a reduction of organization capacity and influences knowledge continuity	Client's project structure, combining project and contract manager roles, may lead to conflicts, task overload, and slower decision-making	
Client organizational size/structure hinders the decision-making		
The conflict between goals and requirements		

Financial related
High cost in development is seen as a major barrier in three case studies. The clients made high investments in the development and implementation of innovations QWR, RTR, and SBR in comparison when using proven methods/products. This can be a source of resistance to the use of innovations. Although the three cases have a similar problem, the difference between RTR and SBR with the IPQ is that the programme has suffered a budget cut which significantly impacts the development and further implementation of innovations. Although QWR and RTR are organized by the same client organization, there are other contributing factors on the financial side of the programme. programme organizations have control of the overall programme but the finances (budget) are influenced by the main organization which is driven by politics that influences within a four-year cycle. The difference between QWR and RTR is the presence of strong leadership from programme organizations is expressed stronger in RTR in comparison with QWR, as revealed from the interviews. This point is discussed in the Enablers to Innovation in the previous section. In addition, innovation in QWR is developed at the project level, while in RTR and SBR the development is designed and organized by one party at the programme level. Since this research is looking at the perspective of companies, the barriers represented in this research depend on the function of these companies in the programme. The implementation of innovations in QWR undergoes a long process before benefits can be gained. There is also a possibility that the development does not succeed, therefore there is no guarantee for work for companies while the cost related to the development of innovation is already incurred. In SBR, the scope enlargement highly influences the overall cost, where innovation cost is included. It resulted in selective works that must be made on the renovation work that could influence the quality.

The second major barrier is the finance-related barrier as indicated in the document review. The programme budget cut in QWR has been the source of financial challenges for the combinations such as high investment and low ROI. Although programme organization owns control of the overall programme, the finances are influenced by the main organization that is driven by politics. The reduction of budget results in less volume of work for the market parties that were earlier promised. It is observed that the source of the financial barrier is a client-related issue.

Table 4.19: Financial related barrier

QWR	RTR	SBR
Reduction of programme budget to 50% than initial budget influences the innovation budget	Substantial investment requires from clients to develop and implement innovation in programme	Development and implementation of innovation in projects is expensive and it requires high investment from clients
Difficult to internalize benefits due to long-term payback period and guarantee of work		
Development of innovation requires high cost at the beginning before benefits can be made		

Time related
This barrier category is created as a result of the interviewees. Time is indicated as a barrier in QWR and RTR. In QWR, interviewees argued that the innovation process takes a considerably long time, in comparison with the certainty of work and potential benefits that are going to be gained by companies. While in SBR, based on the perspective of contractors, the contract duration was long (around 8 years), to acquire few works. This is seen as an undesirable condition for companies. In RTR, time is not indicated as a barrier to innovations.

Market barrier
Market barrier related to the economic crisis is only found in QWR. The COVID-19 crisis had an enormous impact on inflation and the increasing price of materials and it became a barrier to innovations that are currently in the development phase. In combination with budget cuts, it threatens the development of innovations.

4.5. Combining the results from case study

In this section, the findings from three cases are presented. The output from case studies is the elements of innovations consisting of innovation drivers, inputs, preconditions, enablers, barriers, output, and outcomes of innovations. Each of the three cases generates these elements. To be able to come to a meaningful conclusion that is useful for the research, the results from three cases should be combined. This is done by prioritizing the results in two steps. First, the innovation elements such as drivers to innovations, inputs, preconditions, output, and outcomes were taken if they were mentioned in at least two cases. Second, the identified enablers and barriers from 11 interviews were only taken if mentioned by at least 50 % of the total interviewees. This means that only the findings from the documents are taken as results if mentioned by the interviewees. This process results in a generalization of the findings which are explained below.

4.5.1. Innovations elements

Innovation elements drivers, inputs, preconditions, outcome, and output of innovations in multi-projects from three cases are summarized in the following table. The descriptions for each element are self-explanatory. It is noticeable in this research, that the perspective of companies is strongly reflected in preconditions to innovations, such as the financial capabilities of an organization/company influencing the availability of the budget for innovations. When an organization is financially capable, a budget for innovation is also made available and it acts as an input to innovations. Furthermore, strong commitment and intention from clients are prerequisites to innovations. It highlighted the importance of clients to facilitate innovations in multi-projects. Companies need a suitable contract to facilitate the development and innovations in multi-projects. This is because a contract is a key to long-term collaboration and it facilitates knowledge exchange between parties which are crucial to the development and implementation of innovations in multi-projects. These elements are logical since companies are dealing with the impact of lacking these preconditions in innovations.

Table 4.20: Drivers, inputs, preconditions, outcome, and output of innovations in multi-projects

Innovation elements	Descriptions
Drivers	Deliver infrastructure assets at a desired speed, cost, and environmental benefits Increase the quality of the infrastructure assets such as increasing life spans of assets and achieve uniformity and standardization Learning together with the market on certain innovations
Inputs	Large volume of works through bundling of a number of projects Sufficient budget to facilitate innovations Basic knowledge about the innovations comes from other sectors/lab test results/pilot projects
Preconditions	Financial capabilities of an organization/company that are translated into budget Strong commitment and intention to innovations from clients Suitable contract to facilitate innovations with clearly defined contract
Outputs	Innovations that are implemented in projects
Outcomes	Desired quality of infrastructure Efficient and effective infrastructure programme Less impact on environments Less hinder to surroundings

4.5.2. Barriers from case studies

From the interviews of three case studies, 23 barriers were found in practice. These barriers can be further categorized into similar groups determined in the literature study in Chapter 2 which are contracts, regulation, and procedures-related barriers, financial barriers, collaborative barriers, knowledge barriers, technical barriers, market barriers, and cultural barriers.

From 23 barriers, by taking into account the responses that are mentioned by 50% of the interviewees, the top seven barriers are carried forward in this research. They are:

1. Technical Challenge (9/11)
2. Contract form (7/11)

3. Innovation cost (7/11)
4. Client organization size/structure (7/11)
5. Knowledge exchange barrier external (6/11)
6. Time barrier (6/11)
7. Client organization demand (6/11)

It is observed that Technical Challenges are the most important barriers to developing and implementing innovations in projects (9/11). Regardless of the type of innovations, technical challenges still be a concern. Developing innovation is closely related to uncertainty and it introduces risks associated with technical feasibility, reliability, and the ability to deliver the desired outcomes while innovation is crucial in shaping the success of the multi-projects. Innovation requires continual adjustment to achieve the desired outcome.

The next three barriers: the contract form, innovation cost, and client organization size and/or structure, are mentioned by seven interviewees (7/11), after the technical barrier. The contract form is identified by the interviewees as a challenge to the development and implementation of innovations. It is noticeable in two cases in which the framework contracts are utilized but the detail of the agreement influences the outcome of innovations. Innovation requires a substantial investment in research and development, testing, and implementation. This is because of a long-innovation trajectory that involved trial and error and this process requires manpower, machines, and facilities to continue finding and enhancing innovative solutions. Understanding that these costs occur as a part of the innovation process will facilitate the development of innovation. In addition, the size of the client organization and the way it is structured influence the development and implementation of innovation. Although the programme organization is formed within the client's organization, it can not separate the influence of the main organization. It is especially noticeable for public organizations where politics influence decision-making. In relation to this barrier, the demands that come from clients' organizations who are not part of programme organization are challenging. Known as internal organization's stakeholders, their demands and requirements are strict and demanding, therefore, hindering the development of innovations. Knowledge exchange is crucial in the development of innovation. The exchange of knowledge with external parties becomes an obstacle when competition between companies is encouraged. This is because knowledge becomes a valuable aspect of acquiring work. This factor is obvious in the SBR case.

Closely related to the innovation cost is the time barrier. It is indicated by the interviewees that the development of innovations takes a considerable lot of time in comparison to traditional projects where typically proven products are used. Working with innovation requires an adjustment from typical projects. However, time in this research context also means the long duration of a contract becomes a challenge to maintain long-term relations which is prone to the risk of the changes of personnel in both clients and companies organizations. In addition, maintaining a long-term relationship shop requires effort. In addition to time, although knowledge exchange between internal companies organizations, or market combinations effectively works, knowledge exchange with external parties is challenging. This factor is close to the contract form whether collaboration is encouraged in place of competition. The successful development and implementation of innovation in multi-projects can be achieved and enhanced when these barriers are addressed.

Evidently, a notable interrelation exists among the majority of barriers, with clients exerting a significant influence. This connection is particularly evident in aspects like contract forms, organizational size/structure, and clients' organizational demands. This correlation aligns logically with the context, as the interviews are predominantly conducted with companies that possess limited control over these factors, in contrast to barriers like technical complexities and time constraints. It's also worth underscoring that clients play a pivotal role in the innovation process.

Table 4.21 below displays an overview of barriers that were mentioned at least by five interviewees.

Table 4.21: Summary of barriers found in the case study mentioned at least by five interviewees

No.	Barriers	R1RTP	R2RTP	R1QWR	R2QWR	R1SBR	R2SBR	R3SBR	P1RTP	P1QWR	C1SBR	C2SBR	Total
1	Technical challenge	X	X		X	X	X	X	X	X	X		9/11
2	Contract form		X	X	X		X			X	X	X	7/11
3	Innovation cost	X	X		X	X				X	X	X	7/11
4	Client organisational size/structure		X	X	X		X		X	X		X	7/11
5	Knowledge exchange barrier with external parties					X	X	X	X		X	X	6/11
6	Time barrier				X	X	X			X	X	X	6/11
7	Client organisation demand			X	X		X		X	X		X	6/11
8	Scope and/or requirements			X	X	X	X			X			5/11

Table 4.22: Summary of enablers case study mentioned at least by five interviewees

No	Enablers	R1RTP	R2RTP	R1QWR	R2QWR	R1SBR	R2SBR	R3SBR	P1RTP	P1QWR	C1SBR	C2SBR	Total
1	Contract form	X	X	X	X	X	X	X	X	X	X	X	11/11
2	Collaborative effort positive	X	X	X	X		X	X	X	X	X	X	10/11
3	Knowledge exchange with external parties	X	X	X	X	X	X	X		X	X	X	10/11
4	network configuration	X	X		X	X	X		X	X	X	X	9/11
5	Knowledge exchange with internal parties			X	X	X	X	X	X	X	X	X	9/11
6	Clear vision and ambition	X	X			X	X		X				5/11
7	Leadership	X	X				X	X				X	5/11
8	Solid business case	X						X	X	X	X		5/11

4.5.3. Enablers from case studies

There are 15 enablers found in the case study, of which five are taken into further analysis in this research.

1. Contract form (11/11)
2. Positive collaboration effort (10/11)
3. Knowledge exchange with external parties (10/11)
4. network configuration (9/11)
5. Knowledge exchange with internal parties (9/11)

Of all the enablers, the contract form stands out as the primary facilitator for the development and implementation of innovations in multi-project settings. This is due to the role of the contract in enabling clear risk sharing in projects, which is closely intertwined with addressing technical challenges. Furthermore, given the extended duration of the innovation process, a suitable contract form fosters long-term collaboration between clients and market participants, ensuring sustained cooperation throughout the innovation process. Three contract forms are seen in the case study: Framework agreement, Innovations Partnerships, and MC contract.

Positive collaboration efforts play a crucial role in driving innovation. They represent a rational response to the technical challenges that have been identified as obstacles. Establishing a strong partnership between clients, companies, and partner companies serves to mitigate the impact of these barriers. Closely linked to collaboration is the exchange of knowledge with both internal and external parties. Collaboration among companies naturally fosters the sharing of knowledge. Another factor that contributes to innovation is the influence of networks. The case study makes it evident that companies opt to collaborate with others who have previously demonstrated successful collaborative experiences. While not a definitive problem-solving strategy, this approach is supported by the foundation of trust that has been cultivated, thereby enhancing collaborative endeavors. Furthermore, certain of these enablers serve as responses to the barriers. For example, suitable contract forms, which might pose barriers, simultaneously function as catalysts for innovation. Additionally, positive collaboration efforts play a role in promoting the exchange of knowledge with external entities.

Table 4.22 gives an overview of enablers identified by interviewees from semi-structured interviews and were mentioned at least by five interviewees.

4.6. Conclusion from the case study and the next steps

The case study of this research has two goals. First, to identify the innovative elements in data documents and to identify these elements in semi-structured interviews. The innovation elements found in three case studies are drivers, inputs, preconditions, enablers, barriers, output, and outcome of innovations in a multi-project as part of an infrastructure programme. The enablers and barriers are two important outputs of the case study that are going to answer the SRQ4. The elements of innovations found in this case study are going to be used to develop an innovation framework in a multi-project setting.

In total, 33 project documents were analyzed. The documents vary from public client documents and projects' specific documents, including the innovation development documents, progress reports, and tender submission. 11 interviews were conducted with key personnel from engineering companies (8 interviewees) and contractors (3 interviewees), who hold various functions in projects within programme. Methods of data processing and analysis were followed as the procedure provided in Chapter 3.3. Processing interviews in Atlas.ti resulted in a total of 54 codes assigned to the answers provided by the interviewees.

Innovation in projects in infrastructure programme is driven by the motivation to deliver infrastructure assets at desired benefits (efficiency, effectiveness, quality, uniformity, standardization, and learning). Innovation requires inputs such as development and implementation budgets and basic knowledge about innovations. In addition, a large volume of work (such as repetition and a certain number of projects) serves as an important input for innovations in infrastructure programme. Preconditions to

innovations were also identified from case studies. The financial capabilities of organizations or companies are important conditions that must be met before developing and implementing innovations in programme. In addition, strong commitment and intention to innovations from clients and suitable contracts must be also present. The outcome of innovation in projects is typically a technology as product/process innovations that are directly used in the projects to achieve the desired benefits. The outcomes of innovations become the translation of the drivers of innovations in programme.

Aside from identified inputs, drivers, preconditions, outputs, and outcomes of innovations, 23 barriers, and 15 enablers are found in the cases as depicted in Table 4.21 and Table 4.22. After applying prioritization, seven barriers and five enablers are taken into further analysis. The technical challenge was identified as the most important barrier to developing and implementing innovations in projects, regardless of whether the innovations are radical, substantial, or incremental. This is because the development of innovation is an iterative process that deals with uncertainty and risk. The contract form that is suitable for innovations is identified as a major enabler of innovations by companies. A contract such as a framework contract or alliance contract facilitates the risk-sharing mechanism and promotes long-term collaboration.

Next steps
In the next chapter, solutions to the barriers found in the case studies are proposed by incorporating the proposed solutions from interviewees in combination with theory. Furthermore, the innovation elements found in the case study are used to develop a procedure to facilitate the development and implementation of innovation in multi-projects in the form of a framework. The practicability of this framework is going to be assessed and validated by experts from companies.

5

Framework development and expert validations

This chapter aims to develop a framework based on the findings from the case study and literature study and to conduct expert evaluations to assess the applicability of the solutions to practice. This is done, firstly by providing solutions to the barriers found in Chapter 4 before developing a procedure that can be implemented in practice. The procedure to facilitate the development and implementation of innovation comes in the form of a framework. Thus, an answer to SQR5 can be provided. SRQ5:*What procedure can be applied to facilitate the development and implementation of innovation in multi-projects?* This chapter is organized in the following order. Section 5.1 provides recommended solutions to barriers identified in Section 4.5. In Section 5.2 an initial framework is developed with its underlying principle before the implementation of this framework is assessed and verified by experts in Section 5.3. Feedback gained from the experts is incorporated in Section 5.4 before the final framework is presented in Section 5.5 which includes a possible second round of expert validation. The conclusion of this section is provided in Section 5.6.

5.1. Recommended solutions to the barriers

Based on the prioritization made in Section 4.5, the top seven barriers are further analyzed in this research. Each of these barriers is mitigated based on the solutions proposed by interviewees in the case study. If the solutions are not sufficient, results from the literature study in Chapter 2 Table 2.5 are used.

When solutions to the barriers are provided, the enablers to innovations are also considered since they may mirror each other and become solutions to the barriers. In addition, to provide clarity and practicality to the solutions, the barriers are categorized into two. The first group consists of the barriers that the companies can directly put into action and the second group belongs to the barriers that clients have more control over but companies still can influence. The recommended solutions are also categorized based on the source: the case study is coded as C, the literature study is coded as L, and the new proposed-solution is coded as N.

5.1.1. Group I barriers

This first group of barriers consists of technical challenges, knowledge exchange barriers with external parties, and time barriers. The potential solutions to these barriers are provided below.

- **Technical challenge**
  - *Close collaboration with the involved parties in programme (C)*: The innovation process necessitates a robust partnership between clients and companies, where the technical challenges are navigated through an open-minded and optimistic approach. As an example from the case studies, the involvement of technical managers from the client side proves pivotal. Their proactive engagement in discussion demonstrates how diverse perspectives can be harnessed to unravel potential solutions to complex technical challenges. When collaboration form allowed, collaboration is also encouraged between companies, such as seen in the case study. This emphasized that collaboration form is a catalyst for productive collaboration which eventually helps involved parties to solve technical challenges.

- *Develop basic knowledge of technology (C & L)* : Companies should actively cultivate a foundational understanding of technology, with a particular emphasis on staying abreast of the evolving trends within the market. This strategic awareness of market dynamics serves as a reliable compass, indicating the trajectory that the industry is taking. An example is reflected in the emergence of novel automation tools in the current market. Companies can also invest in knowledge development for their workforce by providing training related to technology development. As indicated in the case studies, although the technical challenge is high in the development of technology, it is relatively easy to solve when tools are available and engineers are capable of utilizing them. In addition, the focus must be given to developing systematic company knowledge databases that are easy and accessible to employees working on projects. For example, if a pilot project has been done in other projects with similar technology, the lesson learned from this pilot must be available in the database. This will ensure knowledge continuity within the organization.
- *Create awareness about the innovation process (N)*: As an industry that has worked conservatively for decades, an awareness about the innovation process in the infrastructure industry must be made. This can be done in the form of training, discussion, and presentations to clients' organizations and companies' organizations. These are not limited to the employee involved directly in the development and implementation of the innovation in projects/programme organization, but also the employees that are indirectly involved and potentially become potential stakeholders to the projects/programme. Creating awareness will also help suppress the barriers related to strict requirements, unrealistic demands and expectations, and stakeholders' acceptance.
- *Finding suitable partners (companies) to collaborate with (L)*: Companies do not innovate in isolation but rather collaborate with other actors whose knowledge complements the knowledge gap. Finding suitable partners can be done by utilizing companies' networks, and based on prior successful collaborations. Although this approach is not new in the infrastructure sector, as indicated in case studies, companies should continue networking since there is an increasing trend of small companies rising and bringing niche technologies. In addition, companies should also look beyond the infrastructure sector whose technology may be applicable to infrastructure projects.
- *Collaborate with knowledge institutions (L)*: Companies do not possibly own all the knowledge required in a certain technology. Collaboration with knowledge institutions such as research institutions and universities fills in the knowledge gap that ultimately tackles the technical challenge. Technological universities own abundant research that has potential applications beyond lab testing or pilot projects. Approaching knowledge institutions is a viable way to solve lacking R&D in the infrastructure sector.
- *Propose a suitable time frame (N)*: Innovation development is an iterative process of trial and error, therefore it needs sufficient time to accommodate this process. This can be discussed with the clients during the market consultation, competition dialogue, and processes such as innovation partnership and SBIR

- **Knowledge exchange barriers with external parties**

  - *Utilizing community network to gain knowledge (C & L)*: Closely related to the solution to the technical challenge is utilizing industry knowledge exchange networks such as COB, CROW, and Bruggen platforms that are popularly utilized in the Netherlands. These non-profit networks offer workshops, training, forums, webinars, and conferences where knowledge in the industry's group is shared. Actively contributing to these knowledge exchange networks will enrich the knowledge of technologies that indirectly contribute to the development of innovation. As indicated in the case study, the alignment of goals and vision of the market is made in a similar network forum and it helps the companies not only focus on the direction of the market but also knowledge is shared among the companies through training, workshops, or discussion forums.
  - *Building networks (L)*: Joining the knowledge exchange networks not only enriches the knowledge but also builds networks with other companies. Through networking, companies observe and understand the capability of others that will be useful to future work.
  - *Promoting collaboration in projects (N)*: Companies can help clients choose the type of collaboration that promotes collaboration in projects. As learned from the case study, removing the

competition (such as mini-tender) promotes a unique collaboration between companies in programme, and synergies are created that help facilitate knowledge exchange, eventually, help the achievement of programme goals. Collaboration forms such as alliance and early contractor involvement are some of the two that were indicated by interviewees that help facilitate knowledge exchange and remove competition.

- **Time barriers**
  As indicated in Section 4.5, the time barrier in this research context is the long contract duration and long innovation process. The potential solutions to this barrier are:

  - *Improve collaboration effort in programme (N)*: The innovation process requires time and typically involves extensive duration. Relations in long-term collaborations between clients and companies, as well as internal projects/programme organization, must be maintained. Innovation is a ”leap of faith” that involves risk. It requires positive attitudes from all parties such as trust, belief, transparency, and open communications which can be nurtured such as by organizing regular meetings, utilizing informal communication, and organizing team buildings.
  - *Retain the team in projects/programme (N)*: Personnel change in organisation is unavoidable. However, when a positive atmosphere is maintained in the projects, the employee retains their position in the projects and this helps to retain the team that work on such long-term projects. Providing training on technology development, providing a positive work atmosphere, and the availability of a bonus system are some of the options to keep the employees in the company.
  - *Create awareness about the innovation process (N)*: Similarly to the proposed solution to the technical challenge, creating awareness of the innovation process builds understanding in organizations/companies about the character of innovations. Working with innovations in projects requires a different mindset than traditional projects. This understanding is especially crucial when the innovation is developed from a low TRL level. This means factors such as trial and error must be taken into account before desired results are met and the output of innovation can contribute to the projects/programme goals. Workshops, training, and presentations are some of the ways to create this awareness.
  - *Celebrate small wins (C)*: Instead of focusing only on a long duration of the innovation trajectory, acknowledging and appreciating the achievement of incremental success shall be given. This positive reinforcement can lead to increased motivation, improved team confidence, and a greater sense of progress towards a larger goal, which is the success of innovations. For example, celebrating milestones together with the clients and project teams once reaching completion of the innovation phases, such as seen in the case study.
  - *Negotiating contract duration (N)*: A discussion with the client regarding the contract duration played a crucial role in establishing a shared perspective on the path of innovation. While a standard framework contract usually spans four years, engaging in a dialogue with the clients becomes essential to reach a consensus on the most suitable contract duration. This ensures that the duration was chosen not only supports the development and implementation of innovations in projects but also remains aligned with the programme’s objectives. This discussion can take place during a competitive dialogue or contract negotiation phase.

5.1.2. Group II barriers

The second group of barriers consists of barriers related to contract form, innovation cost, client’s organization size/structure, and client’s organization demands.

- **Contract form**
  From the case study, it is understood that the contract form can serve as a barrier and at the same time also an enabler of innovations. The possible mitigation factors for these barriers are:

  - *Negotiating the detail on contract clause (C)*: Aside from a clear agreement on the risk-sharing mechanism and responsibilities of each party, a contract shall provide a clear clause to avoid variety in interpretation. Innovation elements such as drivers, inputs, preconditions, output, and outcomes of innovations must be considered in the negotiation process. Noteworthy

points are the presence of competition between companies in the development of innovation must be damped as well and the commitment to a budget must be clear.
  - *Using procurement strategy for innovations (L)*: When the need for innovations arise in projects/programme, depending on the innovation type, it is advisable to use competitive dialogue, innovation partnerships, or Small business innovation research. Procurement for innovation in programme is indicated in the literature such as a framework by Lenderink et al. (2022) and its applicability has been seen in the case study. Engineering companies can be in the position to advise the public client about the utilization of procurement for innovations. The suggestion about using certain types of collaboration can be addressed during market consultation or negotiation.

- **High innovation cost**

  - *Using life cycle perspective (C & L)*: As indicated in Section 4.5, innovations in multi-projects are driven by the motivation to reach the desired efficiency and effectiveness. This emphasized that innovation costs must be looked at from a different perspective, such as the life cycle perspective of the infrastructure assets. Although innovation cost is generally incurred high cost at the beginning due to factors such as risk and uncertainty, when the cost is spread out through the life cycle of assets, innovations could be more economical than not using innovations. This approach has been demonstrated in the case study.
  - *Provide a solid business case (L)*: In relation to the life cycle perspective, when innovations are developed and implemented in multiple projects, a solid business case must be presented and agreed upon between clients and companies. The high investment made by clients/companies is spread out over a longer period of time because of the potential long-term benefit of innovations as well the repetitive use of innovation in multiple projects. It also implies that a sufficient volume of demands (for innovations) must be made to reduce the cost of innovation per project. As public clients, wider demands should be made and as companies, wider supply should be made to create market applications.
  - *Increase awareness about innovation process (N)*: Implementing innovations across multiple projects encounters challenges stemming from the industry's conventional project-oriented viewpoint, which may not align with the mindset required for innovation. Understanding the innovation process within the client's organization is crucial, particularly in the context of a robust business rationale. However, a deficiency in awareness concerning the innovation process is evident, largely attributable to the industry's inclination toward established technologies. Consequently, justifying the adoption of innovation becomes intricate when contrasted against the perceived risks and uncertainties associated with existing technologies.

- **Client's organization size/structure**
  The scale and structure of clients' organizations exert an impact on the development and implementation of programme and, therefore also in projects. This influence arises because, even though the programme organization functions as a separate and temporary entity, it maintains its authority through the overarching organization. Consequently, there exists the potential for conflicts to arise between the programme's organization and the primary organization. This situation is a threat to innovations. The possible mitigation of these barriers are:

  - *Actively involving clients in the innovation process (C)*: Awareness of the innovation process has been repeatedly mentioned as a potential solution to the barriers above. Actively involving the clients in the development of innovations is another way to create awareness of innovation because it will increase the understanding of the innovation process. This can be done by engaging clients in discussion as early as possible in the development process (in formal meetings or informal meetings) to think together about solutions to problems in the innovation process, such as seen in the case study. These ways will stimulate positive behavior, motivations, and leadership from the client's representative that can convey the difficulty seen from the projects' level to a higher level in the client's organization.
  - *Clients engagement management (N)*: Considering the high influence of clients' organization, companies should consider a dedicated position to manage the client's internal stakeholders,

focusing on building trust and long-term relationships with clients. An example of a position in client engagement management, is an account manager whose focus is on the client approach, instead of combining this responsibility with project-related matters.

- **Client's organization demands**
  - *Understanding clients perspective (L)*: In relation to the size and structure of clients' organizations, influential stakeholders come potentially from inside clients' organizations who have varying interests and perspectives about the projects/programme. They may have different challenges that may conflict with the programme's objective. The possible solution to understand their perspective is through open communication and discussion with the clients, including the internal stakeholders which include topics such as alignment of goals. When the needs of internal stakeholders are understood through discussion, potential solutions may arise and help the development of innovations. This solution can be combined with the presence of a client engagement manager/account manager whose focus is on the client's side.
  - *Increasing awareness of innovation process (N)*: Providing the clients' organization with training or workshops about the innovation process will help to convey the message about what elements of innovations need to be further developed in projects. This can be done collaboratively with a knowledge exchange network with other companies.
  - *Increasing awareness of industry trends and conditions (N)*: Aside from the awareness of innovations, the traditional perspectives of clients on innovation may come from a lack of understanding of the change of trend in the market (local and global) and increasing innovations capability of companies. Open discussion with clients may help to influence the clients' perspective on innovations therefore their demands' become more aligned with innovations in projects.

5.2. Initial Framework

Now that the barriers are mitigated, a procedure to develop and implement the innovations in multi-projects in infrastructure programme can be built. This section consists of a description of the underlying principle of the framework and an explanation of the framework layout.

5.2.1. Step of framework development and underlying principles

Following the findings from the case study about innovation elements and solutions to the barriers explained in the previous section, a framework is developed to incorporate them. It is generated in several steps. First, taking the conclusion from Chapter 4, in order for innovation to meet desirable outputs and outcomes of programme, inputs, drivers, preconditions, enablers, and barriers must be focused on throughout the projects and programme life cycle, seen in Figure 2.1.3. The programme's life cycle includes innovation development because innovations align with the programme's objectives, making it a logical component of the programme's life cycle. Second, to ensure the practicality of the framework, the recommended solutions proposed in Section 5.1, are further grouped into five categories based on their similarity. These groups are:

- Practical plan 1. Create awareness about the innovation process
- Practical plan 2. Develop basic knowledge of the latest technology trends
- Practical plan 3. Focusing on collaboration efforts in projects/programme
- Practical plan 4. Programme/projects procurement related
- Practical plan 5. Development of business case related

Each of the practical plans has a separate action plan for suppliers and public clients. Third, these five practical plans are separated based on their influence on the programme. The first part is about building a foundation for the innovation process. These are based on the logic that the elements must be present all the time during the innovation process, represented by innovation elements and a clear understanding of the innovation process and available knowledge which must be also present in the organizations. The second part is about what actions are needed to facilitate innovations in programme. Therefore, it is logical that practical action 3, 4, and 5 belongs to this part.

5.2.2. Framework layout

Based on the above-explained steps, the framework is structured in two parts. The first part emphasizes the main focus on innovation elements that must be available all the time, and act as boundary conditions. In addition, proposed plans 1 and 2 are related to the awareness and understanding of the innovation process and technology to support the realization of innovation, therefore, placed in Part I. Each proposed plan has a set of action plans for suppliers and public clients to ensure the implementation of the proposed plan. The second part of the framework is relevant to the programme implementation where the planning, procurement of projects (with innovations), and multiple projects are executed. Part II consist of proposed plan 3,4, and 5. Similar to Part I, a set of action plans for suppliers and public clients are proposed. Fulfilling these action plans collectively is going to mitigate the barriers to innovations indicated in Section 5.1. This initial framework can be seen in Appendix H.

5.3. Expert evaluation

The validity of qualitative research involves assessing the accuracy of the findings as perceived by the researcher and the readers of the research (Creswell, 2014). The expert evaluation aims to discuss the recommended solutions and framework developed in this research with a group of practitioners in the infrastructure sector.

5.3.1. Evaluation approach and expert session

In this research, the expert session was conducted on-location and online with selected experts from companies and public clients. Due to the availability of the personnel during the summer vacation season, the expert session was conducted in three sessions. The first round of expert sessions was conducted with two senior functions in the engineering company, and the second and third rounds were conducted with two public clients. The detail about these experts is depicted in Table 5.1 below. The two experts from the engineering company were chosen based on their expertise, knowledge, and involvement in various projects and infrastructure programme in the field of projects, procurement, and contracting. The experts from the public client-side were selected based on their involvement in the programme.

Table 5.1: Overview of Experts

Expert	Expert Role	Expert session	Date of interview
1. Exp1	Director of Department Engineering Company	Expert session I	24/Aug/23
2. Exp2	Director of Department Engineering Company	Expert session I	24/Aug/23
3. Exp3	Technical Manager from Municipality	Expert session II	05/Sep/23
4. Exp4	Contract Manager from Municipality	Expert session III	06/Sep/23

Expert session protocol

The expert session was conducted in two parts. After a short introduction of the participants and researcher, in the first part, the researcher gave a short presentation about the research topic and the research progress. The presentation ended by presenting the findings from the case study. In the second part, the expert was invited to the online feedback tool Mentimeter to gather feedback about the barriers and enablers of the case study and the proposed action plan.

A list of questions was prepared and asked. These questions were:

1. Do you recognize these elements?
2. Can you rate the top 3 important elements?
3. What items are missing from these aspects?
4. Do you recognize the action plans in this framework?
5. From the proposed solutions, which ones are relevant to the practice?

Although the sessions were conducted on-location, a recording was made upon experts' agreement in Teams Meeting to enable the researcher to review the feedback given by the experts. The sessions were conducted for approximately 60 minutes. During the session, the experts were requested to respond to the questions and discuss the results of each question.

5.3.2. Outcome of first expert session

Barriers and Enablers of innovations

In the first question, the experts were asked about their opinions about the barriers and drivers to innovations found in the case studies. Of the seven barriers, five were recognized: high innovation cost, client organization size, client organization demand, time barrier, and contract form. The technical barriers and knowledge exchange with external parties are not seen as barriers, especially technical challenges. It is because technical issues are relatively easy to solve with the availability of tools and suppliers (engineering companies) have various experts that can solve technical challenges. Client organization size/structure, client demand, and high innovation cost were recognized as the top three barriers by the experts. Both experts mentioned that contract form is highly related to the client organization's demand and the client organization structure in the context of innovation. In practice, a contract does not facilitate space to innovate due to the strict requirements asked by the internal organization. It is further related to the risk-averse behavior influences of public clients that are highly influenced by politics. It is important to note that the experts recognized time as a barrier as well because the environment changes rapidly (such as the norm, regulations, and insight) and when the innovation process is not moving at a faster pace. As a result, the innovations become quickly less relevant over time.

Exp1 and Exp2 also recognized all five enablers of innovations: contract form, positive collaboration effort, knowledge exchange with external and internal parties, and network configuration. According to them, positive collaboration and contract form play a significant role in the development and implementation of innovations. After discussing the findings from the case study, the question was asked "What items are missing in these barriers and enablers?". The incentives for innovations from inside the supplier's organization and clients are lacking which can be related to the way the organization looks at risk (risk averse). In addition, the behavior of people who are involved in the innovations influences the process and it potentially becomes a barrier. This is primarily due to the fact that innovation demands a distinctive mindset. Experts have pointed out that the list is lacking two crucial catalysts: the presence of incentives and financial considerations. Although these two enabling factors were identified during interviews, they were not included in this research's analysis as they were mentioned by only a minority of interviewees.

Applicability to recommended solutions to the barriers

The experts were asked about the applicability of the five action plans for suppliers.

1. **Create awareness about innovation** (Barriers technical challenges and knowledge challenges with external parties, time barriers, high innovation cost, clients' organization demand)
   From the four proposed action plans, experts strongly agreed with the sharing lesson learned about innovation development in knowledge-sharing networks and conducted frequent discussions with internal and external organizations. An action plan for active participation in the community network was agreed upon by Exp2. The action plan to provide training and workshops about the innovation process was seen as unnecessary because engineering companies typically consist of various experts whose knowledge fills up each other. Exp1 and Exp2 indicated that inside the company, there is already a strong network (of expertise) and dedicated innovation managers that manage that process.
2. **Develop basic knowledge of the latest technology trends** (Barriers technical challenges and clients' organization demand)
   Collaboration with research and knowledge institutions and organizing knowledge sharing/presentation were seen by Exp1 and Exp2 as prominent actions to develop knowledge about technology. The other three actions: assigning a knowledge champion for special interest groups, developing a knowledge database, and following the development of technology were agreed by the Exp2.
3. **Improve collaboration effort in projects/programme** (Barrier time and high innovation cost)
   The viable actions for this proposed plan based on the experts were actively networking with other suppliers in order to identify suitable partners to collaborate with. This was based on the fact that to innovate, companies always need partners to be able to learn together in the process, and the process of finding suitable partners was also challenging. Exp1 and Exp2 also agreed to maintain

project teams, especially for such long-term projects/programme. Assigning a dedicated account manager was seen as a viable action, according to experts. However, Exp1 indicated, that instead of assigning it to one person, it should be assigned to a group of people.

4. **Development of business case should contain life cycle analysis, bundling criteria, reasonable time frame** (Barrier high innovation cost and technical challenge)
   For the development of the business case, both experts strongly agreed if suppliers suggest the bundling criteria to the clients and bundling supply for various clients. These two actions are going to facilitate the development and implementation of innovations. Both experts agreed that proposing a reasonable time frame for innovation is needed as well as ensuring that the inputs of innovation are guaranteed.
5. **Programme/projects procurement should consider procurement for innovations** (Barrier knowledge challenges with external parties, time barriers, contract form, clients' organization size/structure, clients' organization demand)
   Three proposed actions were agreed upon by the Exp1 and Exp2. These actions were to negotiate terms and conditions on the contract to avoid disruption in the innovation process, advise the client about the choice of collaboration form to promote innovation during market consultations/ discussion points and ensure the continuity of innovation outside the programme.

The Exp1 and Exp2 agreed that Part II action plans were important and necessary to facilitate the development and implementation of innovations in multi-projects while the action plans from Part I were less attractive/impact for engineering companies.

5.3.3. Outcome of second and third expert sessions

Due to personal circumstances the expert session with clients could not be conducted in one session, but instead in two separate sessions. The results from the clients' expert session are combined in the following.

Barriers and enablers of innovations

Similar to the first expert session, the seven barriers were presented to the experts from public clients and asked if they recognized the barriers. All barriers were recognized by both Exp3 and Exp4 but four barriers were underlined: contract form, high innovation cost, client organization demands, and time barriers. The technical challenge was recognized but not as a highly influential barrier because it can be resolved with the available knowledge and technology. Contract form, on the other hand, was seen by Exp3 and Exp4 as the most important factor in the innovation process. Exp 4 mentioned that it was typically a barrier where the requirements were enforced by various internal stakeholders in the organization in order to avoid high costs. While the value of innovations was recognized in projects, they were deemed appealing primarily when they came with a low cost. In addition, the long duration of the innovation process was also recognized by Exp3 and Exp4 as a barrier because it took an extensive period of time before the innovations could be fully benefited. It included the procurement process for innovations as well as the development of innovations. This process overall influences the perspective of the internal stakeholders to use innovation in projects. In addition to the barriers found in the case study, both experts added that culture influences innovations. It is not only because working with innovations in projects requires a different mindset than regular projects, but also the willingness of the team to open for solutions from external parties (market parties).

Three main enablers were recognized by both experts: positive collaboration effort, knowledge exchange with external parties, and contract form. Based on the experts, collaboration with parties outside the organization such as experts from knowledge institutions, suppliers, and internal stakeholders early in the projects was crucial to facilitate the knowledge exchange. Programme organization continuously engaged them and was transparent as a public organization about the intention of innovations and the goals of the programme. Exp3 and Exp4 mentioned that working with innovation involved not only a long trajectory but also an iterative process that requires trust between parties. When continuous trust is present in the collaboration with these parties, the knowledge exchange is facilitated. Both experts indicated that the contract form was more suitable as a precondition of innovations in multi-projects instead of an enabler.

Applicability to recommended solutions to the barriers
The experts recognized all the five groups of action plans and the following are their regarding each action plan for public clients.

1. **Create awareness about innovation** (Barriers technical challenges and knowledge challenges with external parties, time barriers, high innovation costs, clients organization demand)
   The experts agreed on the action plans related to sharing lessons learned and conducting frequent discussions with internal and external organizations. Exp4 said, ”Such a success story really does help other projects and everyone (in the organization)”. In addition, Exp3 and Exp4 also argued that providing the training will not have an impact on the increasing understanding of the innovation process.
2. **Develop basic knowledge of the latest technology trends** (Barriers technical challenges and clients organization demand)
   The experts supported the action plans: organizing knowledge-sharing sessions, participating in knowledge exchange networks, and collaborating with research and knowledge institutions. However, based on Exp3 providing the training is only beneficial for learning a particular technique.
3. **Focusing collaboration efforts in projects/programme Focusing on collaboration efforts in projects/programme** (Barrier time and high innovation cost)
   The experts agreed on the action plans: maintaining project teams, especially for long-term projects/programme, monitoring the collaboration process, and maintaining relationships with projects/programme teams. Action plan ”Creating a mirror function at the projects level” was not necessary because in practice the project organization of suppliers and public clients was mirrorly formed in any project. Exp3 and Exp4 both mentioned that collaboration was not only limited to the programme organization but also the knowledge institutions that provided dissemination of lessons.
4. **Development of business case should contain life cycle analysis, bundling criteria, reasonable time frame** (Barrier high innovation cost and technical challenge)
   Using a life cycle perspective to justify the innovation cost is seen as an important action for the public clients. Both experts said that building a healthy business case was challenging therefore by looking at the life cycle perspective it offered more opportunities. Exp4 agreed that providing a guarantee of innovations' input such as budgets was equally important for suppliers and public clients because innovations require high up-front investment for both sides and it involved a long innovation trajectory. Although in reality, it is still challenging due to political cycles, a guarantee of innovations budget is necessary for innovations. Furthermore, identifying the capability and capacity of suppliers and providing sufficient time for the development of innovations were agreed upon by Exp3 and Exp4 as actionable plans.
5. **Programme/projects procurement should consider procurement for innovations** (Barrier knowledge challenges with external parties, time barriers, contract forms, clients organization size/structure, clients organization demand)
   Both experts agreed on all proposed action plans related to the procurement. These actions are: selecting a tendering procedure that promotes innovative solutions, using a Project delivery model promoting long-term collaboration between clients-suppliers, eliminating competition, incorporating functional requirements, engaging internal stakeholders to formulate realistic requirements for tender, using award criteria based on quality and/or best value, engaging suppliers at the earliest possible in the programme/projects, make consideration the continuity of innovations outside the programme (intellectual property). It was because all these actions provide a basic form for the successful development and implementation of innovations.

5.4. Adjusting Framework

Based on the feedback from the expert sessions, the framework was adjusted. First, by prioritizing the preferred action plans for suppliers and public clients per the proposed plan. The action was listed as the most preferred action if it was indicated by two experts and the least preferred action if it was only supported by one expert. The actions that were not supported by the expert are eliminated because they do not have practical implications. This process resulted in the order of the actions being different than the initial framework.

1. Practical plan 1. Create awareness about innovation. The action plans for suppliers are listed below from the most preferred to least preferred action.

    - Most preferred actions: (1) Sharing lessons learned of innovation development in professional knowledge sharing network and (2) Conduct frequent discussions with internal organization and external organization
    - Least preferred: Actively participate in community networks for discussion forums, presentations, dialogues
    - Removed: Provide training/workshop on innovation process to organization and clients

2. Practical plan 2. Develop basic knowledge of the latest technology trends.

    - Most preferred actions: (1) Collaborate with research and knowledge institutions (Universities, research institutions) and (2) Organising regular knowledge sharing/presentation sessions and training sessions
    - Least preferred: (1)Assigning a knowledge champion for a special interest group, (2) Developing a knowledge database to share a lesson learned on innovations in projects, (3) Following the latest development of technology in the market (local and worldwide)

    Since the action plans and the response from both sides of experts (suppliers and public clients are the same for practical plans 1 and 2, the action plans are applicable for both.

3. Practical plan 3. Focusing on collaboration efforts in projects/programme.
    Action plans for suppliers:

    - Most preferred: (1) Actively networking with suppliers/organizations to identify suitable partners from the community networks, (2) Maintain project teams, especially for long-term projects/programme duration, (3) Maintain relationships with projects/programme team, (4) Assign a dedicated clients engagement coordinator
    - Least preferred: (1) Actively engage with clients in innovation development

    Action plans for Public clients:

    - Most preferred: (1) Maintaining project teams, especially for long-term projects/programme, (2) Monitor collaboration process (e.g. using collaboration monitor and collaboration coach), (3) Maintaining relationships with projects/programme teams such as celebrating milestones together, using collaboration tools, promoting open communication, nurturing trust, team effort appreciation
    - Removed: Create a mirror function in the projects level

4. Practical plan 4. Programme/projects procurement related
    Action plans for suppliers:

    - Most preferred: (1) Negotiate terms and conditions on the contract to avoid disruption in the innovation process (consider innovation elements), (2) Advise the client about the choice of collaboration form to promote innovation during market consultations/ discussion points with clients, (3) Ensure continuity of innovation outside the programme

    Action plans for Public clients:

    - All proposed plans are preferred by public clients: (1) Selecting a tendering procedure that promotes innovative solutions (2) Using a Project delivery model promoting long-term collaboration between clients-suppliers and eliminating competition, (3) Incorporating functional requirements, (4) Engaging internal stakeholders to formulate realistic requirements for tender, (5) Using award criteria based on quality and/or best value, (6) Engaging suppliers at the earliest possible in the programme/projects, (7) Considering of further use of innovations outside the programme

5. Practical plan 5. Development of business case-related
    Action plans for suppliers:

- Most preferred: (1) Suggest bundling criteria for projects during market consultations/ discussion sessions with clients/ project closure, (2) Suggest bundling supply from various clients
- Least preferred: (1) Propose a reasonable time frame for innovation development, (2) Ensure inputs of innovations are guaranteed

Action plans for Public clients:

- Most preferred: (1) Using life cycle perspective to justify the cost of innovation, (2) Plan sufficient time to develop innovation, (3) Identify capability and capacity of the suppliers and cross-sectoral actors (knowledge and network) by using formal mechanism (market consultation) or informal mechanism, (4) Ensure inputs of innovations are guaranteed
- Least preferred: (1) Create sufficient demands for innovations by identifying assets to be bundled and developing bundling criteria

Second, it is also important to provide clear guidelines when the Innov-Infra framework is used, and who are the responsible parties for each of the actions. For this purpose, several functions that are possibly using the framework were identified and each function was assigned a code:

- Communication Manager (CommM)
- Technical Manager (TM)
- Project Manager (PM)
- Contract Manager (CM)
- Account Manager (AM)
- Innovations Manager (IM)
- Management team (MT)
- Buyer groups (BG)
- Specialists (SS)
- Programme Manager (ProgM)
- Asset Manager (AsM)

A one-page user guideline was written to provide clarity on how to use the Innov-Infra, who is responsible for conducting the Innov-Infra process and the action plan, and when to use the framework. In addition, the innovation elements were categorized as innovation boundaries, with clearer layouts to draw the attention of the users to these aspects. To increase the practicality of the framework, it is equally important to define when suppliers and public clients should use Innov-Infra. Part I of the Innov-Infra framework should be used by organizations involved in multi-projects during the project/programme initiation and Part II should be used during the programme implementation. It is recommended that the organizations assign a person to lead the process of using the Innov-Infra framework. Overall, adjusting the framework, incorporating the responsible person in the framework, and providing the user guidelines, increase the practicality of Innov-Infra.

5.5. Conclusion framework development and expert evaluation

The goal of this chapter is to develop a framework and conduct expert evaluations to assess the practicability of the framework when innovations are developed and implemented in multi-projects in the infrastructure programme.

The identified barriers from the case study that were already prioritized in Chapter 4, resulted in seven barriers to be mitigated. In this chapter, recommendations to mitigate the seven top barriers were proposed. Sets of recommendations are available for each barrier. It is possible that one solution is possible to mitigate multiple barriers. The framework was developed in a few steps. First, the development and implementation must take into account the innovation elements throughout the project/programme life cycle. These innovation elements: inputs, drivers, preconditions, enablers, and barriers, outputs, outcomes of innovations in multi-projects are taken from the findings in Chapter 4, and these are further called innovation boundaries for multi-projects. Second, the proposed solutions to mitigate barriers were grouped into five categories and served as practical plans. These groups are:

- Practical plan 1. Create awareness about the innovation process
- Practical plan 2. Develop basic knowledge of the latest technology trends
- Practical plan 3. Focusing on collaboration efforts in projects/programme
- Practical plan 4. Programme/projects procurement related
- Practical plan 5. Development of business case related

Third, actions are assigned to suppliers and public clients for each practical plan. Furthermore, the framework is divided into two parts based on the impact of the actions on to programme. The first part is boundary conditions for innovation which consists of innovation elements and practical plans 1 and 2. The second part is facilitating the development and implementation of innovations in multi-projects, consisting of practical plans 3,4 and 5. These two parts form the Innov-Infra framework in programme.

To ensure the practicality of the Innov-Infra framework, expert evaluation sessions were conducted with two experts from an engineering company and two experts from public clients, held on three separate occasions. These experts were senior managers in the company whose broad knowledge of innovation and multiple projects and programme. The experts from the client were managers for contract and technical in infrastructure programme. The barriers and enablers from case studies were discussed. Five barriers were recognized by experts: high innovation cost, client organization size, client organization demand, time barrier, and contract form. Two barriers were not recognized by the experts: technical challenges and knowledge exchange. Furthermore, the proposed practical plans with actions for suppliers and public clients were discussed with the experts, which resulted in prioritizing preferred actions for the practice and eliminating the action plans that were not practical.

Based on the feedback from experts, the final version of the Innov-Infra framework was developed as a procedure to facilitate the development and implementation of innovation in multi-projects, accompanied by user guidelines. Innov-Infra framework can be seen in Table 5.2 and the user guidelines can be seen in Table 2. When applying steps and action plans mentioned in this framework, the innovations are facilitated in the multi-projects within the infrastructure programme because the important aspects of innovations in multi-projects were considered. Part I of the Innov-Infra framework should be used by organizations involved in multi-projects during the project/programme initiation and Part II should be used during the programme implementation. It is recommended that the organizations assign a person to lead the process of using the Innov-Infra framework.

Table 5.2: Final Innov-Infra Framework in programme

Innov-Infra Framework				
Part I - Boundary conditions for innovations in programme – To be applied during Projects/programme initiation				
Clarify the following innovation boundaries for (multi) projects: **1. Drivers to innovations:** - Reach desired outputs achieved with innovation (e.g deliver new or renovated infrastructure assets) - Reach desired outcomes (e.g efficiency, effectiveness, quality, learning from projects) **2. Preconditions to innovations:** - Leadership, visions, and commitment - Financial capabilities of organizations - Suitable collaboration form **3. Inputs to innovations:** - Resources (capital investments, knowledge, human resources) - Volume of works or number of projects to form a group of projects **4. Output of innovations:** Proven concept of product/process innovation in project(s) **5. Outcome of innovations:** Desired benefits (e.g efficiency, effectiveness, quality, learning from projects) **6. Aware of enablers and barriers to innovations:** - Enablers: A suitable contract forms, Knowledge exchange with external and internal parties, positive collaboration efforts, influence of networks - Barriers: Contract form, innovation cost, (client's) organization structure/size, knowledge exchange with external parties, time barriers, clients' organization demands, technical challenge	**1. Create awareness about innovation process**	**Action plan 1 for suppliers and public clients** 1.1 Sharing lesson learned of innovation development within internal organization and in external professional knowledge sharing network 1.2 Conduct frequent discussion with internal organization and external organization about innovations process 1.3 Actively participate in community networks for discussion forum, presentations, dialogues	**Responsible person** 1.1 CommM, TM, PM, SS 1.2 IM, MT 1.3 IM, MT, TM, PM	
	2. Developing basic knowledge of the latest technology trends	**Action plan 2 for suppliers and public clients** 2.1 Collaborate with research and knowledge institutions (universities and research institutions) 2.2 Organising regular knowledge sharing presentation/sessions and training sessions 2.3 Assigning a knowledge champion for special interest group of technology 2.4 Following the latest development of technology in the market (local and worldwide) 2.5 Developing a knowledge database to share lesson learned on innovations in projects	**Responsible person** 2.1 SS, TM, MT 2.2 SS, TM, MT 2.3 IM, MT 2.4 IM, MT, BG, SS 2.5 IM, MT	
Part II – Facilitate the development and implementation of innovations – To be applied during Project/programme implementation				
3. Focusing on collaboration efforts in projects/programme	**Action plan 3 for suppliers** 3.1 Actively networking with other suppliers/organisations to identify suitable partners from the community networks 3.2 Maintaining project teams especially for long-term projects/programme duration 3.3 Maintaining relationship with projects/programme team (e.g celebrating milestone together, using collaboration tools, promoting open communication, nurturing trust, team effort appreciation) 3.4 Assigning a dedicated Account Manager/team for a client 3.5 Actively engaging with client(s) in the innovation development and implementation	**Responsible person** 3.1 TM, SS, PM, CM, MT 3.2 MT 3.3 MT, AM, PM 3.4 MT 3.5 AM, PM, TM	**Action plan 3 for public clients** 3.1 Maintaining project teams especially for long-term projects/programme 3.2 Maintaining relationship with internal projects/programme team and with suppliers' team (e.g, using collaboration tools, promoting open communication, nurturing trust, team effort appreciation, using collaboration coach) 3.3 Monitoring collaboration process internal and external organization during the projects/programme (e.g collaboration monitor, team assessment)	**Responsible person** 3.1 ProgM, PM 3.2 ProgM, CM, PM 3.3 ProgM, PM
4. Programme/projects procurement should consider the following: • Procurement for innovations • Project delivery model support long-term collaboration • Utilizing functional requirement • Continuity of use of innovations • Award criteria supporting innovations	**Action plan 4 for suppliers** 4.1 Negotiating term and conditions on the contract to avoid disruption on innovation process (consider innovation boundary in Part I) 4.2 Advising the client about the choice of collaboration form to promote innovation during market consultations/ discussion points with clients 4.3 Ensuring the continuity of innovation outside the programme	**Responsible person** 4.1 CM 4.2 MT, IM, CM 4.3 MT, IM	**Action plan 4 for public clients** 4.1 Selecting tendering procedure that promoting innovative solutions (competitive dialogue, innovation partnerships, SBIR) 4.2 Using Project delivery model promoting long-term collaboration between clients-suppliers and eliminating competition (framework agreement, alliance, two stages approached with early contractor involvement) 4.3 Incorporating functional requirements 4.4 Engaging internal & external stakeholders to formulate realistic requirements for tender 4.5 Using award criteria based on quality and/or best value 4.6 Engaging suppliers at earliest possible in the programme/projects 4.7 Making considerations the continuity of innovations outside the programme	**Responsible person** 4.1 CM, ProgM 4.2 CM, ProgM 4.3 CM, TM, PM, AsM 4.4 ProgM, PM, TM 4.5 CM, ProgM 4.6 CM, ProgM 4.7 ProgM, CM, BG, AsM
Practical plan 5. Development of business case should consider the following: • Lifecycle analysis • Criteria to bundle/group projects • Reasonable time frame for innovations development	**Action plan 5 for suppliers** 5.1 Advising bundling supply for various public clients 5.2 Suggesting criteria for grouping projects (e.g locations, types of assets, complexity of assets/works) during market consultations/ discussion sessions with clients/ project closure 5.3 Proposing a reasonable time frame for innovation development 5.4 Ensuring inputs of innovations are guaranteed from internal organization	**Responsible person** 5.1 MT, IM, AM 5.2 MT, IM, AM, SS, PM 5.3 PM, TM 5.4 MT, PM	**Action plan 5 for public clients** 5.1 Using life cycle perspective to justify the cost of innovation 5.2 Planning a sufficient time to develop innovation (consider trial and error process/learning process) 5. 3 Identifying capability and capacity of the suppliers and/or cross sectoral actors by using formal mechanism (market consultation) or informal mechanism 5.4 Ensuring inputs of innovations are guaranteed from organization 5.5 Creating sufficient demands to innovations by identifying assets to be bundled and develop bundling criteria	**Responsible person** 5.1 ProgM, CM, AsM 5.2 CM, PM, TM 5.3 CM, PM 5.4 ProgM, PM 5.5 ProgM, CM, PM, AsM

Table 5.3: Innov-Infra user guidelines

Innov-Infra User Guidelines

General Information

- Innov-Infra framework is a two parts framework, highly recommended to be used by organizations when innovation(s) is considered to be used and/or going to be developed/implemented in multi-project/programme.
- Part I should be used during programme/project initiation and Part II during programme/project implementation
- The responsible person listed in this framework are using the abbreviation as per following functions but not limited to:
  - Technical Manager (TM)
  - Project Manager (PM)
  - Contract Manager (CM)
  - Account Manager (AM)
  - Innovations Manager (IM)
  - Management team (MT)
  - Communication Manager (CommM)
  - Buyer groups (BG)
  - Specialists (SS)
  - Programme Manager (ProgM)
  - Asset Manager (AsM)
- The above functions are the typical function in the organization who potentially use the Innov-Infra in multi-projects in suppliers and/or public clients' organization
- It is highly recommended to assign one person in the organization (can be from the list of function above) to lead the process of using Innov-Infra
- It is possible to assign the action plans to multiple responsible persons in the organization
- Suppliers in this context are market parties, consist of engineering and consultancy companies, contractors, and companies supply chain
- It is suggested for organization to add steps and action plans when necessary
- More explanation about underlying principle of this framework is available in TU Delft education repository and search for thesis Savitri Dinar Wulandari

Follow these following steps to use the Innov-Infra Framework:

1. Start from Part I, top left corner "**Clarify the following innovation boundaries for (multi) projects**"
   Ensure these factors are presence and clear in your projects/programme. These are the boundary conditions for innovations in (multi)projects. Assign responsible persons to the presence of innovation boundary. For example, Management team or programme manager.
2. Move to step **1. Create awareness about innovation process** and Step **2. Developing basic knowledge of the latest technology trends**
   Ensure the action plans are fulfilled to facilitate the development and implementation of innovations. When the action plan is not applicable to organization, ensure alternative plans are created to generate the desirable outcome. For example, action plan "1.1 Sharing lesson learned of innovation development internal organization and in professional knowledge sharing network". When the organization does not have experience in projects with innovations, other alternative action plan can be inviting other organizations to share their experience on innovation development.
3. Move to Part II Step 3, 4, and 5 and choose the action plans depending on organization.
   It is not necessary to follow the order of step 3,4,5 but following the order of action plan per step is preferred.
   For example, a responsible person who leads the Innov-Infra process from an Engineering company chooses step 4. Programme/projects procurement as the first step in Part II. The action plan "4.1 Negotiate term and conditions on the contract to avoid disruption on innovation process (consider innovation boundary in Part I)" must be first followed before moving to action plan "4.2 Advising the client about the choice of collaboration form to promote innovation during market consultations/ discussion points with clients".
   Ensure each action plan is assigned to a responsible person(s).
4. Ensure all the steps in Part II are followed and action plans are completed. When the action plan is not applicable to organization, ensure a replacement of action plan is made, assigned it to a responsible person, and complete the action.
5. It is recommended for organization to organize a regular review of utilization Innov-Infra depending on the intensity of the projects/programme i.e Bi-weekly or monthly.
6. When all steps are followed, it is recommended to re-do the process from Part I and Part II to ensure the steps and actions plan are still valid, especially in the long-term multi-projects.

6
Discussion

This chapter has three goals: first to discuss the research finding in Section 6.1, to describe the practical and theoretical implication in Section 6.2, and third, to explain the reliability and validity of this research in Section 6.3, and finally, to discuss the limitation of the research in Section 6.4.

6.1. Discussion of the results

This section discusses the research findings in relation to the research objectives, the research question, and sub-research questions by comparing them to the literature found in Chapter 2.

6.1.1. Infrastructure programme and innovations in programme

From the case study in Chapter 4, it is indicated that the infrastructure programmes are motivated by the need to organize multiple (renovation) interrelated projects in order to provide safe infrastructure assets. As a multi-project organized by a public organization, compliance with safety becomes a primary goal of the infrastructure programme. Programme, therefore, acts as a means for the government as a public organization to translate its goals. Organizing these projects individually will not be able to achieve programme's goal. The findings are therefore aligned with the theoretical definitions of programme from Shehu and Akintoye (2009), the goal of infrastructure programme such as mentioned by Tromp et al. (2022), Hertogh et al. (2018), and Spijkerboer et al. (2015), and the characteristics of programme which focuses on the realization of the benefit/goals/value of organization (Pellegrinelli et al., 2007; Thiry, 2004; Shehu and Akintoye, 2009; Eweje et al., 2012; Frederiksen et al., 2021). The findings suggest that the need to use innovations arises in order to achieve the primary goals because innovations help complex multi-year projects become effective and efficient through standardization and uniformity as well as expedite the learning between projects. This emphasizes that innovations enable infrastructure programmes to achieve their goals.

Innovations are typically developed and implemented at the project level. Consistent with the literature, innovations in the infrastructure sector can be defined as a new improved product and/or process that are different or have not yet existed in the sector which leads to the improvement in the functionality of technical performance of infrastructure assets. It is evident as well from the case study that innovations in the infrastructure occur as a result of interaction from various actors such as seen in Winch (1998) model. Actors (companies) in the market form a consortium/combination with other companies based on mutual interests, goals, and, trust, that is typically based on previous successful collaborations. Innovations can be mandated in the programme by the clients (top-down approach), where innovations' development is facilitated in programme from low TRL until becoming commercial products/processes, and innovations can also arise due to the opportunity to improve the programme's performance (bottom-up approach). Lundberg et al. (2019) pointed out that the top-down innovation is less progressive than the bottom-up approach. This is confirmed in the case studies where the innovation development, mainly as a result of the top-down approach, involves a long trajectory (long development trajectory, long(er) contract duration). As a result, time is indicated as a barrier to innovation by suppliers. In addition, from the three programme's case studies, innovations in the multi-projects are a result of the top-down approach, where innovations become a condition to achieve the programme objectives. In addition, the literature indicates that the majority of innovations in the infrastructure sector come from

suppliers (Pries & Dore, 2005). The phenomenon of bottom-up innovation is not seen in the infrastructure programme, where innovations are motivated by the programme objective.

In contrast to the literature, the innovations in multi-projects are categorized as radical to substantial indicated with lower TRL level, instead of incremental. Thus, innovations in multi-projects characterized by low TRL levels become a unique character in the infrastructure programme. The choice made by the public clients to organize the innovations at a programme level is an attempt to move away from a project-based approach. Innovations in programme can also be seen as a strategic move in order to achieve the desired outcome or make progress as a result of inter-related projects. From the case studies, it is evident that demand from clients can be bundled, agreed with the research report from EIB (2022). Similar to innovations in other sectors, regardless of whether the innovations are radical, substantial, or incremental, innovations in the infrastructure sector undergo iterative processes that involve trial and error before being successfully implemented on a large(r) scale (Lenderink et al., 2022; Garcia and Calantone, 2002). This has been seen in one of the case studies where the innovation could not be further implemented because the technical limit of the assets had been reached.

Principal engineering companies and contractors are identified as significant actors in the innovation process due to their comprehensive expertise and capacity to align supply with demand (Winch, 1998). This research's case studies highlight their role in harmonizing various innovation requirements, which subsequently drives the innovation process within multi-project contexts. In the realm of innovation, market parties usually seek out partners by leveraging past successful partnerships, shared objectives, and partners' capability of filling knowledge deficiencies. This phenomenon, as observed both in the case study and supported by existing literature, highlights the collaborative nature of innovation processes (Rutten et al., 2009; Jones et al., 2022; Nguyen, 2023).

6.1.2. Innovation process

This research reveals that the development and implementation of innovations in programme only succeed when the elements in the innovation process such as pre-conditions, inputs, and drivers are available and guarded, the barriers are managed, and the enablers are facilitated to produce desired outputs and outcomes. Findings on these elements are summarized as follows:

Preconditions and inputs to innovations

Precondition to innovations is defined as a condition that must be fulfilled before the innovation process starts. Preconditions essentially ensure that the environment is suitable or ready for the intended action. This significantly differs from inputs to innovations, where resources, data, information, or materials are required to initiate a process, activity, or task. Inputs provide the necessary resources to carry out the operation effectively. Preconditions and inputs are closely related to each other but different and it results in deviation in the answer from interviewees when preconditions and inputs were asked.

The findings in Section 4.5 indicate three preconditions to innovation. First, the financial capability of an organization serves as a precondition to innovation. It is due to innovation requiring a high investment upfront and high cost is incurred at the beginning of the process. This factor is not indicated as a precondition based on the literature but it is more related to the input of innovation. Second, strong commitment and intention for innovation from clients is needed as a solid ground for innovations therefore the development and implementation are facilitated. The second precondition from this research is closely related to the presence of leadership in the programme organization to the innovation process, as indicated by Xue et al. (2014) and Hartmann (2006). This can be seen as a strong programme organization support to the programme, which interestingly was observed in programme organized by the same public clients but different programme organizations (Case QWR and RTR). The leadership of programme organization was strongly identified in RTR in comparison with QWR. The third precondition is a suitable contract form to facilitate close collaboration for innovations. The preconditions observed in case studies can be related to the theoretical background which indicates that collaboration and culture are preconditions to innovations. Collaboration elements from the theory (Xue et al., 2014; Vosman et al., 2023) can be related to the finding that indicated a suitable contract form as a facilitator to collaboration in innovations. It is because, without it, the coopetition in the multi-projects is hindered. It can be concluded that although preconditions to innovations based on the findings are

not directly the same as the theoretical background, strong commitment and intention from clients and a suitable contract form are related to the theory. The financial capability of the organization (public clients and suppliers), however, is not indicated earlier in the literature and, therefore is a new addition to the preconditions in multi-projects.

The findings suggest that a large volume of work through bundling of projects serves as a catalyst for innovation. Interestingly, this aspect, previously overlooked in the literature, may be attributed to the predominant focus within the existing literature on single project perspective rather than the broader context of multi-project. This element becomes one of the important findings of this research because innovation development needs certainty of application on a larger scale before the innovation process starts to be developed by suppliers in multiple projects. In addition, a sufficient budget for innovations and possessing basic knowledge serve as inputs to innovation based on the findings. These two factors confirmed the findings from the literature (Ozorhon and Oral, 2017; Xue et al., 2014), where innovation needs input capital resources, human resources, and knowledge to start the process.

Barriers and enablers
During the innovation process in a multi-project, barriers, and enablers are continuously encountered by clients and suppliers which creates a dilemma to innovate. This research categorizes seven groups of barriers and enablers to innovations derived from the literature which are contract and regulation-related, collaboration and cultural-related, financial-related, technical-related, knowledge exchange-related, client-related, and market-related. From the literature study, 27 barriers and 21 enablers to innovations in the project were found. Therefore, the relevance of multi-projects as part of the infrastructure programme is lacking. From the case study, seven barriers and five enablers are found based on the cases in the infrastructure programme.

The findings revealed a barrier that was not indicated earlier in the literature study: time-related barriers. The time-related barrier is indicated as the long-duration process of innovation and the length of the programme. Furthermore, the technical challenge is indicated in the case study as the number one barrier in multi-project. The technical challenge experienced in the multi-projects in this research context refers to the iterative process of innovation and deals with uncertainty while the time-related barrier is indicated as the long-duration process. These two barriers are debatable because technical and time are two characteristics of innovation instead of barriers that have to be mitigated. The innovation process always involves technical challenges, as supported by existing literature (Lundberg et al., 2019). These challenges are an inherent part of the process and cannot be eliminated entirely. They necessitate time for innovation to mature by addressing uncertainties and effectively managing risks. Striking a balance is crucial, where time plays a role in facilitating development rather than impeding it. In practice, technical obstacle is often viewed more as challenges than a barrier. They can be readily addressed through the availability of tools and the diverse expertise found within engineering companies. This stands in contrast to findings in the literature, which highlight that a lack of comprehension of technical subjects and technologies among project teams can negatively impact the successful implementation of innovation (Gambatese and Hallowell, 2011; Hart et al., 2019; Nguyen, 2023).

This research confirms the barriers to innovation that are known from the project literature. First, depending on the form, a contract can be a barrier as well as an enabler of innovation. A contract is intended to facilitate the development and implementation of innovation because it nurtures a long-term relationship between clients and suppliers, reflecting the extent to which the requirements are clear, as well as ruling the risk-sharing mechanism and responsibilities (Hart et al., 2019; Lenderink et al., 2022; Vosman et al., 2023). However, the findings suggest that although a suitable contract is chosen, the detail of the contract influences the outcome of innovation, for instance, the presence of competition to acquire works in programme. This result is aligned with the study from Ozorhon et al. (2010) and Oesterreich and Teuteberg (2016) which discuss the downside of competition, especially in the sector where the profit margin is relatively tight. The presence of competition due to the collaboration form, hinders further knowledge exchange among external parties that are necessarily needed in the development of innovation in multi-project. A similar argument about the knowledge change has been made by Kulatunga et al. (2006) and Jones et al. (2022). Therefore, it is clear that a suitable contract form plays a crucial role in facilitating innovations in multi-projects.

High innovation cost is identified as a financial-related barrier to innovation such as seen in the literature (Adriaanse, 2014; Arnoldussen et al., 2017; Hart et al., 2019). This is in contrast to the suggestion from the literature which mentioned that grouping projects helps to overcome the issue of scale-up, where challenge related to the cost of innovation is frequently seen in a single project. It is because, grouping projects in programme requires a much higher upfront investment (in comparison to a single project) and incurs upfront high costs, although these costs are spread out over a long duration instead of a single project. Furthermore, similar to the literature, this study shows that clients' organization size and structure, especially in public organizations, is a barrier to innovation because it influences the decision process. The public organization consists of various (internal) stakeholders that influence projects. Their varying demands and requirements can be conflicting in relation to innovations and programme. This becomes problematic because the programme organization is still part of the main organization and therefore the stakeholders can influence the programme. Working with innovation requires different ways of working that need to be understood by not only programme/projects organization but an organization in general. Increasing awareness and understanding about innovations and alignment of goals between these stakeholders in the organization is therefore needed for innovation to succeed in programme (Nguyen, 2023; Saad et al., 2023). It is because the achievement of programme success means the achievement of public organization goals (to provide safe infrastructure assets).

Aside from contract form as an enabler to innovation, a positive collaboration effort is indicated in the findings that help to facilitate innovations. This factor is indicated in the literature as a system and culture that support innovations such as a positive mindset to innovations, providing a supporting environment (Ozorhon et al., 2010, Dulaimi et al., 2005; Hart et al., 2019). These factors are found again during the research in the form of close collaboration between clients and suppliers such as open communication, nurturing and the presence of trust, clear responsibilities, and utilizing regular meetings. In relation to collaboration, suppliers also prefer to utilize the networks to find suitable partners to collaborate with, based on past successful experiences. It is because trust has been nurtured and cooperation between parties is facilitated through the alignment of goals between them, as also mentioned in the literature by Bossink (2004), Hart et al. (2019), and Vosman et al. (2023).

Output and outcomes to innovations
As indicated in the literature study, the output of innovations is a product/process that is used to achieve the outcome of innovations. The investment made by clients and suppliers is expected to yield output that is directly measurable (Obwegeser & Muller, 2018). Innovations are developed to a higher TRL level and implemented in a multi-project to achieve the desired standardization and uniformity and help achieve the programme objective. The output of innovations is in the form of intellectual property and technology as a product that reaches higher TRL levels (Ozorhon and Oral, 2017; Obwegeser and Muller, 2018). Although direct measurement to programme objective is difficult to measure in this research, because programmes have not been completed, the desired output of innovation in these projects is achieved. The outputs of innovations observed in the case study are the proven technologies, applied at the large(r) scale. The impact of these outputs can be assumed to contribute to the achievement of the intended benefits of innovations in infrastructure programme.

Framework to innovation in programme
Relying on the findings from the case study explained in Section 4.4, a potential procedure to facilitate the development and implementation of innovations has been generated in the form of the Innov-infra framework in programme. The framework contains two core steps: establishing boundary conditions for innovations (Part I) and facilitating the development and implementation of innovations (Part II). This framework incorporates the innovation elements such as those found in the project literature (Xue et al., 2014; Ozorhon et al., 2010).

The case study suggests that there are common elements and pathways in the innovation process in both multi-project and single-project scenarios. However, multi-project environments offer an advantage by fostering the development of innovations, a benefit that is absent in single-project settings. The innovation development process in programme may be similar to other multi-project approaches (such as portfolio), depending on the extent of the outcome multi-project approaches are intended to. Thus,

the procedure developed in this research is also applicable to other types of multi-projects. This research, therefore, provides a theory of the development of innovations beyond single project boundaries that commonly are seen in the infrastructure sector.

6.2. Research implications

This research adds value to both practical and scientific knowledge within the infrastructure industry. At the scientific level, this research delves into the impact of innovations in infrastructure programme and factors that influence the development and implementation of innovations in multi-projects. The literature reviews in this research have covered the elements of the innovation process in infrastructure industry (Winch, 1998; Hart et al., 2019; Ozorhon and Oral, 2017; Xue et al., 2014; Rutten et al., 2009; Nguyen, 2023; Halman, 2018; Wamelink and Heintz, 2014; Bossink, 2004; Tromp et al., 2022), programme in infrastructure (Frederiksen et al., 2021; Hertogh et al., 2018; Rijke et al., 2014; Delaney, 2014; Yan et al., 2019; Tromp et al., 2022; Shehu and Akintoye, 2009; Pellegrinelli et al., 2007;EIB, 2022) and procurement for innovations (Lenderink et al., 2022; Grandia and Volker, 2023; Uyarra et al., 2014; Wamelink and Heintz, 2014). Typically, research delves into innovations at the project level, leading to literature that primarily concentrates on discussing project-based innovations. Conversely, existing literature on programmes predominantly revolves around programme governance. With the scarce availability of literature that investigates innovation in infrastructure programme, this research has contributed to the academic by addressing this gap by qualitatively investigating the factor that contributes to the development and implementation of innovation in programmes. By employing a qualitative method with multiple case studies, barriers and enablers to innovations in programme are identified based on the perspective of suppliers. The suppliers (engineering companies and construction companies) as system integrators have a crucial role in the development of the innovation process because of their capability to gather market parties' innovative capability and the demand of clients in order to provide meaningful solutions for the clients. This study, therefore, has added to the literature on how the innovation process goes in the infrastructure programme by investigating the innovation elements. Based on these identified elements in the infrastructure programme, a qualitative framework, the Innov-infra framework in programme is produced and can be used as a guideline for public clients and suppliers when involved with innovations in programme. Thus, overall this study adds to the current literature on how innovations can be facilitated in multi-projects as part of the infrastructure programme.

At the practical level, within the context of the Innov-infra framework, this research provides insights into the specific components of innovation that warrant careful consideration when employed in multi-project settings. Furthermore, the research puts forth action plans for both clients and suppliers to effectively address barriers that arise during the innovation process. Remarkably, these action plans possess broad applicability across various types of innovations, underscoring their practical value. As indicated in Innov-Infra Framework in Figure 5.2, when innovation is initiated in programme, public clients should focus on preconditions to innovations: financial capabilities of the organization, vision, and commitment to innovations, and select a suitable contract form. During the programme implementation, starting from procurement for projects/programme, clients and suppliers must ensure the inputs are available throughout the projects. In addition, during the programme implementation, effort must be made to overcome the barriers by focusing on the action plans. Clients and suppliers must focus on enablers such as fostering a positive collaboration effort, facilitating knowledge exchange with internal and external parties, strengthening the network, and ensuring the contract used stimulates long-term collaboration and facilitates the development of innovations. This guideline however should not become the sole guidance for the practice. Instead, clients and companies shall continuously identify barriers during the programme implementation. When the desired benefits of innovations in projects are met and projects are fully realized in programme, programme will reach programme closure. The innovations as an output of an infrastructure programme become commercialized products/processes that can be used in other projects/programme.

6.3. Research assessment

To produce a high-quality research outcome, reliability, validity, and generations of the findings must be conducted (Yin, 2009). The research assessment for qualitative social science research consists

of reliability, construct validity, internal validity, and external validity. Each of these assessments is discussed in the following.

6.3.1. Reliability

Research reliability includes maintaining consistent procedures, including recording and documenting the case study approach, establishing protocols, and creating a research database for reproducibility by other researchers (Yin, 2009). To reproduce this research, Section 3.1 and Section 3.3 explained the case study protocol. The interview preparation can be read in Section 3.2.2 and the interview protocol can be seen in Appendix D. A careful review of the interview transcript to ensure minimum mistakes occurred in the transcription was also conducted. When analyzing the interview, the codes must be consistently applied to the transcripts to avoid shifting the data interpretation. The list of the code can be found in Appendix E. Finally, since this research is conducted by one researcher, multiple cross-checks must be performed by the researcher (Creswell, 2014). When these steps are performed, the research should be internally consistent, stable over time, and consistent therefore reproducible (Creswell, 2014). In addition, a secured database for the research is utilized by the researcher to store research data with limited access. Such research data are interview transcriptions, audio recordings, and reviewed project documents. However, due to the confidentiality agreement with companies and interviews, these data are destroyed once this research is completed.

6.3.2. Validity

Qualitative research validity is assessed through three methods: construct, internal, and external validation (Creswell, 2014; Yin, 2009).

Construct validity

Ensuring construct validity entails determining the accurate operational measures for the study. In this research, the process of establishing construct validity was carried out across three distinct phases. The research variables (innovation elements) were defined in Phase I of this research where various sources were utilized to define the measures. The source of the literature study was scientific articles, official research documents from research institutions, and official government websites. Project documents and semi-structured interviews are two types of data used in the empirical phase of this research. By utilizing multiple data, consistency and common themes are identified (Creswell, 2014). Finally, in phase III expert session was conducted by the researcher involving three practitioners to review the developed framework of this research. This research has performed these three phases of construct validity.

Internal validity

Internal validation concerns the causal relationship whereby certain conditions are believed to lead to another condition Yin (2009). This research employed a method of pattern matching and explanation buildings during the analysis of the case study performed in Chapter 4. Pattern matching is where the causal relationship proposed in this research is valid. This is done by conducting interviews. For example, the interviewees were asked whether innovation contributes to the progress of the infrastructure programme. The majority of the answers indicated a positive contribution of innovation to programme, this indicates a high validity. Pattern matching can be also seen by cross-checking the answers of interviewees in the same case. For example, the interviewees were asked about the enablers and preconditions of innovations. A low internal validity results from the different interpretations of interviewees to the question than what was intended, therefore leading to different answers. The researcher therefore cross-checked the answers from other interviewees from the same case before the answers were taken into account (by assigning appropriate codes). As indicated in Section 4.5, the results of the case studies were taken if the innovation elements were found in two cases and if the elements were mentioned by more than half of the interviewees. Applying this filter also demonstrates a pattern matching between cases and leads to high validity of the research.

The second part of internal validation concerns explanation building where a phenomenon is explained, a presumed series of causal connections pertaining to it, or how or why behind the occurrence (Yin, 2009). In this research, as an example, innovations in programme in three case studies act as a conditional goal to achieve programme primary objective. The comparison between the three case studies

was also made in Section 4.4 to draw explanations and conclusions.

In addition, to address the inference made by the researcher, the expert session was held to gain feedback and practicability of the framework by asking experts whether the findings were recognized and the proposed actions by the researcher are applicable in practice. This procedure suggests that the observed patterns were consistent, potentially diminishing any influence stemming from the researcher's interpretation. Throughout the sessions, the experts were inquired about their thoughts on the recommended action plans, which were intended to address the identified barriers and facilitate the innovations in multi-projects. This approach can be viewed as a means to assess the validity of the causal relationships.

External validity
External validation focuses on how the findings can be generalized to other contexts and settings. The detailed description of the research design allows the replicated of similar studies by other researchers (Creswell, 2014). However, the generalization made by the researcher must be tested. The final framework presented by the researcher is intended for general application therefore suitable for other types of programme. To test the generalization and replication logic, during the expert session, experts were asked about the possible application of the proposed solutions in other programmes where innovations are utilized. Since the innovations are applied in projects, the applicability of the solutions is not only limited to multi-projects in programme but also other types of multi-project approaches such as portfolio approach and mega projects.

6.4. Research limitations

Reaching the completion of this research, research limitations are identified as follows:

- This research is conducted in one engineering company. Generally, companies (engineering companies and contractors) operate based on projects and have a limited view of programme perspective in comparison to the public clients who are usually more familiar with programme context.
- This research only includes the perspective of companies as suppliers in the process of developing and implementing innovations in multi-projects within the infrastructure programme. This made the opinion of public clients isolated from the solutions. The public client's perspectives are taken from the written public documents and interpreted by the researcher.
- This research employs qualitative methods which rely on the interpretation of the researcher for data analysis and interpretation of answers by interviewees. This factor is therefore indicated as a limitation of the research.
- The availability of cases where one company is involved in programme where innovations were developed and used is rare. This made the research limited to the three selected cases available in a company.
- Due to the data confidentiality, contractual matters are shared only at the minimum with the researcher. In addition, the majority of the interviewees are executing the projects and are not involved in the contractual matters of the projects. This results in a limited view of the research in relation to the procurement phase of the projects. To mitigate this issue, the expert session was conducted with the company's senior managers who own knowledge about the procurement phase of the case studies.
- The framework comprises solutions designed in a general manner to facilitate widespread practical application. Consequently, it might potentially lack a certain level of detail.
- The framework in this research is validated only with the internal experts from the company where this research is conducted and public clients who were involved in programmes' case study. If the validation had included other companies and other clients on other programmes, the applicability of the framework will be stronger.
- This research did not go into the details of the procurement of innovation such as the procurement process and the influence of selection and award criteria on the innovation developments.

7

Conclusions and Recommendations

This research has the main objective to investigate the role of innovations in the infrastructure programme and enhance the comprehension of the factor and mechanisms that play a crucial role in the development and implementation of innovations in the infrastructure programme. In the final chapter of this research, the final conclusions are presented by answering the sub-research questions based on the literature and findings in this study which leads to answering the main research question. This chapter is structured as follows: Section 7.1 provides conclusions of this research where the answers to sub-research questions are provided before finally answering the main research question. Section 7.2 focuses on the recommendations for practice. This chapter ends with recommendations for future research in Section 7.3.

7.1. Conclusions

This research's main objective is to enhance understanding of the factors and mechanisms that play a crucial role in the further development and implementation of innovations in the infrastructure programme by looking at the perspective of suppliers. This research has presented the innovation process in the infrastructure programme and its elements that contribute to the development and implementation of innovations in multi-projects as part of programme. This includes the barriers and enablers of innovation found in practice based on suppliers' perspectives. The literature study conducted and the findings of this research are used to answer the main research question.

7.1.1. Answering sub-research questions

SRQ1. What are the goals and characteristics of infrastructure programmes?

To answer this sub-research question, a literature study was conducted in Chapter 2 and the answer was formulated in combination with findings from the case study in Chapter 4. Literature indicates that the goal of the infrastructure programme is driven by compliance to provide safe and reliable infrastructure to the users. This primary goal is logical since the owner of (public) infrastructure is the government. In this research context are government bodies, such as the Directorate of Public and Water Works (Dutch: Rijkswaterstaat), provinces, and municipalities. This makes the infrastructure programme a compliance-oriented programme. However, the infrastructure programme's goal can be also a realization of government strategic objectives such as sustainability and circularity. Infrastructure programme also has secondary goals which occur for two reasons. First, programme aims to add values that can not be realized if programme is not formed. An example is multi-function infrastructure as a result added value to programme. Second, primary programme goals only can be realized if by the fulfillment of the secondary goal. This goal serves as a conditional goal to a primary goal. An example of this conditional goal is the utilization of innovation to achieve the desired effectiveness and efficiency of an infrastructure programme. In practice, these secondary programme goals arise due to a variety of reasons. Such as seen in the SBR programme, the secondary programme's goal was to facilitate the implementation of HPC in the steel bridge renovations. Without the client's vision to implement HPC on the bridges' deck, programme was not formed. The secondary goal in SBR has an added value because the programme aims to build the knowledge of market parties in relation to HPC implementation, which was at that time scarce. Furthermore, the infrastructure programme can be distinguished into

ten characteristics and can be found in Section 2.1.4. These characteristics have helped to select the appropriate case study for this research and build an understanding of the infrastructure programmes.

SRQ2. What are the contributions of innovations in the infrastructure programmes?

Based on various literature in Chapter 2, innovation is in general needed in infrastructure to tackle the increasing complexity of infrastructure projects and societal challenges. The motivations for innovations vary, in relation to projects, companies, or sectors. Innovations in compliance-oriented and vision-lead programmes contribute to delivering projects and improving infrastructure quality, effectiveness, and efficiency. This aligns with the findings from the case study in Chapter 4, which indicated that innovation is a means to achieve programme objectives. The innovations developed and implemented in multi-projects within programme enable the multiple renovation projects to be executed faster and more efficiently and to deliver safe infrastructure assets with less hindrance to the surrounding. Programme also necessitates standardization and tailored solutions to ensure predictable operation and maintenance of infrastructure assets. This reason is also found in practice where innovations enable the organization to achieve uniformity and standardization in tunnel operation and maintenance. In short, embracing innovation is essential not only for the sector's growth and success, but as well the infrastructure programme, enabling it to tackle challenges, improve the performance of programme, and meet the demands of society and programme goals effectively.

SRQ3. What are the barriers and enablers to innovations based on the literature?

To answer this question, a comprehensive list of barriers and enablers to innovations in projects is produced based on the literature, as seen in Chapter 2 Section 2.4. There are 27 barriers and 21 enablers found and categorized into seven groups: contract and regulation, financial, collaboration and cultural, technical, knowledge sharing, client-related, and market-related. Table 2.5 shows the list of these barriers and enablers, which are not programme specific. The barriers to innovations are rooted majority due to project-based settings, as a typical approach in the infrastructure sector which often causes scaling difficulties. The literature argues that programmes become necessary to overcome this challenge. The barriers are sometimes interconnected, for example, the absence of collaboration effort with a network of actors results in a lack of a knowledge-sharing mechanism with external parties. Another example is the lack of demand for innovation from public clients shapes the market toward a competitive market. Suppliers also acknowledge the risks associated with innovations, which might not lead to immediate returns. Thus, effective integration of innovations in programmes requires well-defined strategies.

SRQ4. What are the barriers and enablers to innovations identified in programmes?

In Chapter 4, the second phase of this research, an analysis of three case studies has been conducted, including reviewing 33 project documents and conducting 11 semi-structured interviews with suppliers (engineering and consultancy companies and contractors). The analysis resulted in 23 barriers and 15 enablers found in practice. The outcome of this phase is seven barriers and five enablers to innovations in programme based on suppliers' perspectives in multi-projects. The seven barriers are technical challenge, contract form, innovation cost, client organization size/structure, knowledge exchange with external parties, time barrier, and client organization demand. Some of these barriers in multi-projects are similar to single projects but the time barrier is a new barrier that was not earlier identified in the literature review in Chapter 2. The enablers of innovations in programme are contract form, positive collaboration effort, knowledge exchange with external parties, network configuration, and knowledge exchange with internal parties. Among those barriers and enablers, the technical challenge is the top barrier to innovation, and a suitable contract form is identified as the top enabler to innovation in programme.

SRQ5. What procedure can be applied by suppliers and public clients to facilitate the development and implementation of innovations in multi-projects?

To answer this question, the barriers found in Chapter 4 were first mitigated by providing recommended solutions, sourced from the interviews, the literature study, and additional solutions proposed by the researcher to mitigate the barriers. The conceptual framework based on the literature study in Chapter

2 was further developed based on the solutions. This was done by incorporating the framework of innovation by Ozorhon and Oral (2017) and Xue et al. (2014), as a foundation to develop a potential procedure to facilitate the development and implementation of innovation in multi-projects. This results in two parts framework: Part I contains the necessary foundation for innovation which includes the innovation elements found in Chapter 2 and Chapter 4, acts as an innovation boundary, and two practical plans and Part II contains the action plans to facilitate innovations which consist of three practical plans focus on collaborations, projects/programme procurement, and development of business cases. After validation by four experts, a final framework called Innov-Infra Framework in Programme was created and ready to use in practice by suppliers and public clients, as seen in Table 5.2, accompanied by guidelines, as seen in Table 2. By following the steps of in Innov-Infra Framework, the development, and implementation of innovation in programme are facilitated. It is because in each step, the innovation elements, consisting of inputs, drivers, preconditions, enablers, barriers, outputs, and outcomes of innovations, are considered all the time. The framework puts concrete actions for suppliers and public clients to overcome the barriers that may arise during the process. Using Innov-Infra will allow the innovations to be further developed and implemented in multi-projects that contribute to the achievement of programmes' goals.

7.1.2. Answering main research question

All the necessary steps to answer the main research question have been performed by answering the sub-research questions. In phase four of this research, a discussion about the research has been done and its limitation was addressed in Chapter 6. To close this research, the main research question is answered.

How can innovations be facilitated in a multi-project setting, in order to contribute to the achievement of programmes' goals?

The goal of this research was to enhance understanding of the factors and mechanisms that play a crucial role in the further development and implementation of innovations in the infrastructure programme. Currently, the innovations are developed and implemented in multi-projects as a means to achieve the primary goal of the infrastructure programme, to provide safe infrastructures to the users. The innovations used in the infrastructure programme vary from low TRL level to high level. Regardless of the TRL level of innovations, barriers are continuously encountered by public clients and/or suppliers especially when the elements of innovations are neglected. Preconditions must be present before the innovation process begins. Strong commitment and intentions from public clients are needed for innovations to succeed. In addition, clients and suppliers must have financial capability because innovations typically require a higher investment in advance compared to proven-concept technology. Innovation requires close collaboration between actors participating in the development of innovation. Therefore, a suitable collaboration form, that promotes collaboration must be chosen. Competition among suppliers therefore should be avoided in the process. Innovations in programme require inputs such as a sufficient budget, basic knowledge of technology, as well a sufficient volume of work through bundling of the projects. It is one of the distinctions of innovations with a single project approach, that innovation developed in programme is facilitated because it is (potential to be) used in a large volume of works and/or multiple times, therefore, the cost can be spread out through multiple projects. Considering these elements, innovation development and implementation in multi-projects are facilitated. Innov-Infra framework is recommended to be used in practice as a guide to these processes since the early phase of the programme. Innov-infra offers action plans for suppliers and public clients to mitigate potential barriers to innovation in order to meet the desired outputs and generate outcomes of innovations in multi-projects. Although this research does not measure the direct impact of innovations on programme goals, the swift development and implementation of innovation in multi-project collectively deliver positive contributions to the success of delivering safe infrastructure assets as the goal of the infrastructure programmes.

7.2. Recommendations to practice

While integrating the Innov-Infra framework in practice by clients and suppliers facilitates the development and implementation of innovation in multi-projects, specific recommendations to actors involved in programme are provided in this section based on the findings of this research.

7.2.1. Recommendations to suppliers

- Clear ambitions of organization to innovations
  Literature and this research has shown numerous benefits of innovation to projects' such as effectiveness and efficiency of projects. Despite the continuous obstacles and dilemmas experienced by suppliers in the innovation process, innovations are needed for the advancement of the companies and the infrastructure sector. Suppliers, therefore, need to have a clear ambition about innovations and continue to stimulate innovations in projects because it provides a roadmap for strategic innovation efforts in companies by aligning resources, motivating employees, and positioning the company for growth and competitiveness in the sector.
- Cultivate innovation culture in the organization
  Although innovation has been a part of most suppliers' culture, working with innovation needs a different mindset and sometimes involves an extensive amount of innovation trajectory. This requires a different way of working which involves an iterative learning process. Understanding the innovation process is needed but also requires ongoing actions such as the presence of leadership, training, and development for the workforce, feedback, and a recognition system that helps the organization to operate and value innovations. It is advised for suppliers to cultivate an innovation culture in the organization
- Actively share knowledge about innovations
  In infrastructure, innovation perspectives vary among stakeholders, emphasizing the need for ongoing knowledge sharing about the innovation process and its application to advance the industry. Theoretical models like Winch and the triple helix highlight that innovation development thrives on interaction among actors. In multi-project settings, continuous knowledge exchange among stakeholders (clients, suppliers, knowledge institutions) through community networks is vital. Public knowledge sharing enhances sector-wide comprehension of innovation, fostering a perception of innovation as a means to achieve goals rather than mere project expenses. Engaging in such a knowledge community, including clients, promotes a better understanding of each other's needs and interests, facilitating the proposal of mutually beneficial solutions.
- Utilizing Innov-Infa framework as a basis framework when innovation is used in multi-projects
  The framework is built based on the case study of the infrastructure programme in the Netherlands. It implies its high relevance to future projects that are advised, designed by an Engineering company, and executed by contractors. Engineering companies as system integrators in infrastructure systems can act both as advisors to public clients. When innovation is indicated in programme or multi-projects, it is advisable to focus on the innovation elements for the successful implementation of innovations. Engineering companies can also advise public clients on the type of collaboration form that enables collaboration and knowledge exchange between actors that are essentially needed in the successful implementation of innovations.
- Bundling supply of innovations to clients
  One of the barriers to innovation is the high investment that has to be made by clients and/or suppliers to innovations. Although this barrier is still seen in the programmatic approach, bundling methods are still a promising step. Market parties such as Engineering companies can advise public clients to facilitate market parties to bundle and offer innovative solutions to multiple public clients such as by adjusting procurement policy and procedures. Bundling the supply of innovations from market parties is not only going to solve the high investment cost by companies but also help the achievement of programmes' goals.

7.2.2. Recommendations to public clients

- Strong commitment to innovations in multi-projects
  This research highlights that clients own significant influence in driving innovations, which play a crucial role in achieving infrastructure programme goals. Public clients organization often already have visionary ambitions for innovation, but these need to be translated into concrete commitments and actionable plans throughout the organization, including programme organization. Without such commitment, the programme becomes vulnerable to political changes, potentially impacting the innovation process essential for achieving programme objectives.
- Educating the organization about the innovation process
  Public clients as the biggest clients in infrastructure need to have a clear understanding of the

innovation process from multiple layers in the organization. Especially when working in a programmatic approach where projects are interrelated and organizing such programme needs intra-organization collaboration, support from the internal organization (who are possibly also stakeholders) is required. it is because working with innovation requires a different way of working. One must remember that programme is also a translation of an organization's goal. Thus, facilitating the innovations in programme ultimately a realization of the government's goal.

- Close collaboration with suppliers and stakeholders at the early stage of programme
  Case studies have demonstrated that involving suppliers at the early stage of programme such as the design stage, results in the swift implementation of innovations. This is because suppliers and stakeholders can work, discuss and address requirements that are needed to facilitate innovation in order for a programme to succeed.
- Using a collaboration form that promotes long-term relationship
  Together with the increasing understanding of the innovation process, it is desirable if the client moves to relational collaboration. This is because working and using innovations involves a long-term process where positive collaboration effort must be maintained.
- Bundling demand of innovations
  As a public organization that operates using public funds, public clients should look to bundle the demand for innovations among public clients. This would make innovation more attractive in terms of cost because the high cost will be shared with more public organizations while as a result the quality of infrastructure is improved.

7.3. Recommendation for future research

By reviewing the limitations of this research, opportunities for future research arise as follows:

- This research has investigated the perspective of suppliers in the development and implementation of innovation in multi-projects as part of infrastructure programmes. This provides a number of possibilities for other researchers such as investigating the perspective of clients and the combination of clients and suppliers.
- As indicated in Section 6.4, other potential research is to investigate the development and implementation of innovations in other types of programmes outside the infrastructure sector such as housing and school programme or area development programme.
- Another possibility for other researchers is to investigate innovations in the other types of multi-project approaches, such as the portfolio approach.
- Due to limited case studies, this research used qualitative methods, relying on the researcher's interpretation. Future research can explore quantitative techniques like surveys for more data on innovation elements, potentially yielding more precise, unbiased results.
- The Innov-infra framework proposed in this research was only tested with four experts in the infrastructure sector. The applicability of this framework is therefore still widely open for other programmes.
- The scope of this research did not include investigating the procurement for innovations. As it has been indicated in this research, contract form plays a crucial role in the development and implementation of innovations in programme. Potential research is to investigate the details of procurement for innovations in multi-projects.
- A recommendation for stimulating innovation development and implementation is to bundle supply and demand. While the programme bundles demand under one client, further research on bundling demand across multiple clients and supply of innovation remains an intriguing solution for addressing infrastructure challenges.
- The case study shows a top-down approach to innovation demand in the infrastructure programme. Exploring a bottom-up approach to innovation in a multi-project setting and studying various types, including incremental innovations, is an intriguing possibility.
- This research did not explore how innovation affects the achievement of the programme's goals since the programmes are still in progress. Consequently, there is an opportunity to study the influence of innovations once the programmes have been concluded.

References

Adriaanse, A. (2014). *Bruggen bouwen met ict* [Rede uitgesproken bij de aanvaarding van het ambt van hoogleraar Bouprocesintegratie ICT aan de fac. Construerende Technische Wetenschappen van de Universiteit Twente op donderdag 9 oktober 2014]. Universiteit Twente.

Amsterdam, G. (2022). *Uitleg programma*. https://www.amsterdam.nl/parkeren-verkeer/bruggen-kademuren/uitleg-programma/

Amsterdam, G. (2023a). *Programma aanpak wegtunnels q1-2021*. Retrieved May 2, 2023, from https://openresearch.amsterdam/nl/page/72341/programma-aanpak-wegtunnels-q1-2021

Amsterdam, G. (2023b). *Tunnels: Onderhoud en verkeerscentrale*. Retrieved May 2, 2023, from https://www.amsterdam.nl/projecten/tunnels/

Arnoldussen, J., Groot, P., Halman, J., & Zwet, R. (2017). *Innovatie in de bouw: Opgaven en kansen*. Economisch Instituut voor Bouwnijverheid.

Artto, K., Martinsuo, M., Gemnden, H. G., & Murtoaro, J. (2009). Foundations of program management: A bibliometric view. *International journal of project management*, *27*(1), 1–18.

Barlow, J. (2000). Innovation and learning in complex offshore construction projects. *Research Policy*, *29*(7), 973–989. https://doi.org/10.1016/S0048-7333(00)00115-3

Benmansour, C., & Hogg, K. (2002). An investigation into the barriers to innovation and their relevance within the construction sector. *18th annual ARCOM Conference*, *2*, 677–686.

Bindelrs, S. (2021). *Utilizing the potential of infrastructure renovation programs: An explorative research on how goals can be controlled and synergies can be utilized in infrastructure renovation programs* (Master's thesis). Delft University of Technology.

Blismas, N., Sher, W., Thorpe, A., & Baldwin, A. (2004). A typology for clients' multi-project environments. *Construction Management and Economics*, *22*(4), 357–371. https://doi.org/10.1080/01446190310001649047

Bossink, B. A. (2004). Managing drivers of innovation in construction networks. *Journal of construction engineering and management*, *130*(3), 337–345.

Cantarelli, C. C., & Genovese, A. (2021). Innovation potential of megaprojects: A systematic literature review. *Production Planning & Control*, 1–21. https://doi.org/10.1080/09537287.2021.2011462

Chesbrough, H. W. (2003). *Open innovation: The new imperative for creating and profiting from technology*. Harvard Business Press.

Coenen, T. B. J., Visscher, K., & Volker, L. (2023). A systemic perspective on transition barriers to a circular infrastructure sector. *Construction Management and Economics*, *41*(1), 22–43. https://doi.org/10.1080/01446193.2022.2151024

Consultant, T. E. (2023). *Amsterdam tunnel renovation program*. Retrieved May 1, 2023, from https://tec-tunnel.com/projects/amsterdam-tunnel-renovation-program/

Creswell, J. (2014). *Research design qualitative, quantitative and mixed method approaches* (Vol. 4). Lincoln: Sage Publication, Inc.

Debouwcampus. (2023). *Vervanging and renovatie infrastructuur*. Retrieved April 6, 2023, from https://debouwcampus.nl/

Delaney, J. (2014). *Construction program management*. CRC Press.

Dubois, A., & Gadde, L.-E. (2002). The construction industry as a loosely coupled system: Implications for productivity and innovation. *Construction Management and Economics*, *20*(7), 621–631. https://doi.org/10.1080/01446190210163543

Dulaimi, M. F., Nepal, M. P., & Park, M. (2005). A hierarchical structural model of assessing innovation and project performance. *Construction Management and Economics*, *23*(6), 565–577. https://doi.org/10.1080/01446190500126684

Dulaimi, M. F., Y.Ling, F. Y., Ofori, G., & Silva, N. D. (2002). Enhancing integration and innovation in construction. *Building Research & Information*, *30*(4), 237–247. https://doi.org/10.1080/09613210110115207

Edquist, C., & Zabala-Iturriagagoitia, J. M. (2012). Public procurement for innovation as mission-oriented innovation policy [The need for a new generation of policy instruments to respond to the Grand Challenges]. *Research Policy*, *41*(10), 1757–1769. https://doi.org/https://doi.org/10.1016/j.respol.2012.04.022

EIB. (2022). *Ifd in de infrastructuur*. Retrieved May 5, 2023, from https://www.eib.nl/publicaties/ifd-in-de-infrastructuur/

EUComission. (2018). *Guidance for innovation procurement*. https://ec.europa.eu/transparency/regdoc/rep/3/2018/EN/C-2018-3051-F1-EN-MAIN-PART-1.PDF

EuropeanUnion. (2014). *Directive 2014/24/eu of the european parliament and of the council of 26 february 2014 on public procurement and repealing directive 2004/18/ec.*

Eweje, J., Turner, R., & Mller, R. (2012). Maximizing strategic value from megaprojects: The influence of information-feed on decision-making by the project manager [European Academy of Management (EURAM 2011) Conference]. *International Journal of Project Management*, *30*(6), 639–651. https://doi.org/https://doi.org/10.1016/j.ijproman.2012.01.004

Fathi, M. S., Anumba, C., Carrillo, P., & Aziz, Z. (2007). Construction programme management-current context. *Proceedings of the 2007 ASCEICIB Construction Research Congress. Academic Event Planners*, 6–8.

Frederiksen, N., Gottlieb, S. C., & Leiringer, R. (2021). Organising for infrastructure development programmes: Governing internal logic multiplicity across organisational spaces. *International Journal of Project Management*, *39*(3), 223–235. https://doi.org/10.1016/j.ijproman.2021.01.004

Gambatese, J. A., & Hallowell, M. (2011). Factors that influence the development and diffusion of technical innovations in the construction industry. *Construction Management and Economics*, *29*(5), 507–517. https://doi.org/10.1080/01446193.2011.570355

Gann, D. M., & Salter, A. J. (2000). Innovation in project-based, service-enhanced firms: The construction of complex products and systems. *Research Policy*, *29*(7), 955–972. https://doi.org/https://doi.org/10.1016/S0048-7333(00)00114-1

Garcia, R., & Calantone, R. (2002). A critical look at technological innovation typology and innovativeness terminology: A literature review. *Journal of Product Innovation Management*, *19*(2), 110–132. https://doi.org/https://doi.org/10.1111/1540-5885.1920110

Geraldi, J., Teerikangas, S., & Birollo, G. (2022). Project, program and portfolio management as modes of organizing: Theorising at the intersection between mergers and acquisitions and project studies. *International Journal of Project Management*, *40*(4), 439–453. https://doi.org/10.1016/j.ijproman.2022.03.005

Gomez Chica, T. (2022). Exploring governance mechanisms for inter-organizational collaboration in dutch infrastructure programmes.

Grandia, J., & Volker, L. (2023). *Public procurement: Theory, practices and tools*. Springer Nature.

Halman, J. I. M. (2018). Met zekerheid in onzekerheid: Over innovatie en het nemen van innovatierisico's.

Hansen, M. T., Birkinshaw, J., et al. (2007). The innovation value chain. *Harvard business review*, *85*(6), 121.

Hart, J., Adams, K., Giesekam, J., Tingley, D. D., & Pomponi, F. (2019). Barriers and drivers in a circular economy: The case of the built environment. *Procedia Cirp*, *80*, 619–624.

Hartmann, A. (2006). The context of innovation management in construction firms. *Construction Management and Economics*, *24*(6), 567–578. https://doi.org/10.1080/01446190600790629

Hertogh, M. J., Bakker, J. D., der Vlist, M. J. V., & Barneveld, A. S. (2018). Life cycle management in upgrade and renewal of civil infrastructures. *Organization, Technology and Management in Construction: an International Journal*, *10*(1), 1735–1746. https://doi.org/doi:10.2478/otmcj-2018-0005

Hobday, M. (2000). The project-based organisation: An ideal form for managing complex products and systems? *Research Policy*, *29*(7), 871–893. https://doi.org/https://doi.org/10.1016/S0048-7333(00)00110-4

Hwang, S. (2008). Utilizing qualitative data analysis software: A review of atlas.ti. *Social Science Computer Review*, *26*(4), 519–527. https://doi.org/10.1177/0894439307312485

Infranea. (2019). *Infranea supports tec in future-proofing the tunnels of amsterdam*. Retrieved 2019, from https://infranea.com/en/project/infranea-supports-tec-in-future-proofing-the-tunnels-of-amsterdam/

Jansen, F., & van der Vlist, A. (2011). *De winst van innoveren: Innovative en prestaties van bouwbedrijven*. Economisch Instituut voor Bouwnijverheid.

Jarvenpaa, A. T., Larsson, J., & Eriksson, P. E. (2022). How public clients control systems affect contractors innovation possibilities. *Construction Innovation*. https://doi.org/10.1108/CI-03-2022-0054

Jones, K., Mosca, L., Whyte, J., Davies, A., & Glass, J. (2022). Addressing specialization and fragmentation: Product platform development in construction consultancy firms. *Construction Management and Economics*, *40*(11-12), 918–933. https://doi.org/10.1080/01446193.2021.1983187

Koopmans, M. (2021). Optimizing the management of risks related to product innovations in the construction industry, in the context of the innovation partnership.

Kulatunga, U., Amaratunga, D., & Haigh, R. (2006). Construction innovation: A literature review on current research.

Lam, T., & Gale, K. (2014). Highway maintenance: Impact of framework agreements upon project financial performance. *Construction Management and Economics*, *32*(5), 460–472. https://doi.org/10.1080/01446193.2014.892628

Lenderink, B., Boes, J., Halman, J. I. M., Voordijk, H., & Dore, A. G. (2022). The development of a typology and guideline for selecting innovation-encouraging procurement strategies in civil engineering. *Innovation: The European Journal of Social Science Research*. https://doi.org/10.1080/13511610.2022.2094898

Lenderink, B., Halman, J. I. M., Boes, H., & Voordijk, H. (2020). A method to encourage and assess innovations in public tenders for infrastructure and construction projects. *Construction Innovation*, *20*(2), 171–189. https://doi.org/10.1108/CI-05-2019-0044

Liu, T., & Tang, L. (2020). Open innovation from the perspective of network embedding: Knowledge evolution and development trend. *Scientometrics*, *124*(2), 1053–1080. https://doi.org/10.1007/s11192-020-03520-7

Liu, Y., van Marrewijk, A., Houwing, E.-J., & Hertogh, M. (2019). The co-creation of values-in-use at the front end of infrastructure development programs [Delivering Value in Projects and Project-Based Business]. *International Journal of Project Management*, *37*(5), 684–695. https://doi.org/https://doi.org/10.1016/j.ijproman.2019.01.013

Lundberg, M., Engstrom, S., & Lidelow, H. (2019). Diffusion of innovation in a contractor company: The impact of the social system structure on the implementation process. *Construction innovation*. https://doi.org/doi-org.tudelft.idm.oclc.org/10.1108/CI-08-2018-0061

Lutt, S. (2021). *An exploration of a programmatic delivery approach for programmes in the construction sector* (Master's thesis). University of Twente.

Lycett, M., Rassau, A., & Danson, J. (2004). Programme management: A critical review. *International Journal of Project Management*, *22*(4), 289–299. https://doi.org/https://doi.org/10.1016/j.ijproman.2003.06.001

Martinsuo, M., & Hoverfallt, P. (2018). Change program management: Toward a capability for managing value-oriented, integrated multi-project change in its context. *International Journal of Project Management*, *36*(1), 134–146.

Martinsuo, M., & Lehtonen, P. (2007). Program and its initiation in practice: Development program initiation in a public consortium. *International Journal of Project Management*, *25*(4), 337–345.

Mazzucato, M. (2011). The entrepreneurial state. *Soundings*, *49*(49), 131–142.

Murray-Webster, R., & Thiry, M. (2000). Gower handbook of project management, chapter 3, managing programmes of projects.

Nguyen, M. V. (2023). Barriers to innovation in construction organizations of different sizes: A case study in vietnam. *Engineering, Construction and Architectural Management*.

Nicholas, J. M., & Steyn, H. (2017). *Project management for engineering, business and technology*. Taylor & Francis.

Noktehdan, M., Shahbazpour, M., Zare, M. R., & Wilkinson, S. (2019). Innovation management and construction phases in infrastructure projects. *Journal of construction engineering and management*, *145*(2), 04018135.

Obwegeser, N., & Muller, S. D. (2018). Innovation and public procurement: Terminology, concepts, and applications. *Technovation*, *74-75*, 1–17. https://doi.org/https://doi.org/10.1016/j.technovation.2018.02.015

OECD & Eurostat. (2018). *Oslo manual 2018*. https://doi.org/https://doi.org/https://doi.org/10.1787/9789264304604-en

Oesterreich, T. D., & Teuteberg, F. (2016). Understanding the implications of digitization and automation in the context of industry 4.0: A triangulation approach and elements of a research agenda for the construction industry. *Computers in Industry*, *83*, 121–139. https://doi.org/https://doi.org/10.1016/j.compind.2016.09.006

OGC. (2011). Managing successful programmes.

Ortt, J. R., et al. (2010). Understanding the pre-diffusion phases. *Gaining momentum managing the diffusion of innovations*, 47–80.

Ozorhon, B., Abbott, C., Aouad, G., & Powell, J. (2010). Innovation in construction: A project life cycle approach. *Salford Centre for Research and Innovation in the Built Environment (SCRI) Research Report*, *4*, 903–1012.

Ozorhon, B., & Oral, K. (2017). Drivers of innovation in construction projects. *Journal of construction engineering and management*, *143*(4), 04016118.

Pellegrinelli, S. (1997). Programme management: Organising project-based change. *International Journal of Project Management*, *15*(3), 141–149. https://doi.org/https://doi.org/10.1016/S0263-7863(96)00063-4

Pellegrinelli, S., Partington, D., Hemingway, C., Mohdzain, Z., & Shah, M. (2007). The importance of context in programme management: An empirical review of programme practices. *International Journal of Project Management*, *25*(1), 41–55. https://doi.org/10.1016/j.ijproman.2006.06.002

Pianoo. (2023a). *Innovatiepartnerschap*. Retrieved July 1, 2023, from https://www.pianoo.nl/nl/inkoopproces/aanbestedingsprocedures/innovatiepartnerschap

Pianoo. (2023b). *Raamovereenkomst*. Retrieved July 1, 2023, from https://www.pianoo.nl/nl/inkoopproces/aanbestedingsprocedures/raamovereenkomsten#Wat_is

PMI. (2021). *A guide to the project management body of knowledge*. https://www.pmi.org/pmbok-guide-standards/foundational/PMBOK

PMI. (2023). *Bim and digital twin applied at amsterdam road tunnels programme*. https://tec-tunnel.com/wp-content/uploads/2021/03/BIM-Digital-Twin-en-digitale-omgeving-AWA.pdf

Pollack, J., & Anichenko, E. (2022). The ten differences between programs and projects, and the problems they cause. *Engineering Management Journal*, *34*(2), 314–328. https://doi.org/10.1080/10429247.2021.1900661

Pries, F., & Dore, A. (2005). A century of innovation in the dutch construction industry. *Construction Management and Economics*, *23*(6), 561–564. https://doi.org/10.1080/01446190500040349

ProvinceNoordHolland. (2023). *Ifd-bouwen katalysator voor circulariteit en bereikbaarheid*. https://www.noord-holland.nl/Actueel/Archief/2023/Januari_2023/IFD_bouwen_katalysator_voor_circulariteit_en_bereikbaarheid

Rijke, J., van Herk, S., Zevenbergen, C., Ashley, R., Hertogh, M., & ten Heuvelhof, E. (2014). Adaptive programme management through a balanced performance/strategy oriented focus. *International Journal of Project Management*, *32*(7), 1197–1209. https://doi.org/https://doi.org/10.1016/j.ijproman.2014.01.003

Rijkswaterstaat. (2019). *Toekomstige opgave rijkswaterstaat: Perspectief op de uitdagingen en verbetermogelijkheden in de gww-sector*. https://www.pianoo.nl/sites/default/files/media/documents/Rapport-toekomstige-opgave-rijkswaterstaat-mei2019.pdf

Rijkswaterstaat. (2022). *Innovatieagenda 2030 samen sneller met focus innoveren*. https://www.rijkswaterstaat.nl/zakelijk/innovatie

Rijkswaterstaats. (2015). *Vernieuwen van bruggen, tunnels, sluizen en viaducten*. Retrieved April 1, 2015, from https://www.magazinesrijkswaterstaat.nl/zakelijkeninnovatie/2015/04/leren-van-renoveren

Rijkswaterstaats. (2023a). *Va16: Renewal of van brienenoord bridge*. Retrieved May 1, 2023, from https://www.rijkswaterstaat.nl/wegen/projectenoverzicht/a16-vernieuwen-van-brienenoordbrug

Rijkswaterstaats. (2023b). *Vernieuwen van bruggen, tunnels, sluizen en viaducten*. Retrieved May 1, 2023, from https://www.rijkswaterstaat.nl/over-ons/onze-organisatie/vervanging-en-renovatie

Rogers, E. M. (2010). *Diffusion of innovations*. Simon; Schuster.

RoyalHasKoningDHV. (2023). *Renovatie kademuren aobwegesermsterdam*. Retrieved January 5, 2023, from https://www.royalhaskoningdhv.nl/nl-nl/projecten/renovatie-kademuren-amsterdam

Russo, R. d. F. S. M., Sbragia, R., & Yu, A. S. O. (2013). Determining factors in the unforeseeable uncertainty management in innovation projects. *2013 Proceedings of PICMET13: Technology Management in the IT-Driven Services (PICMET)*, 623–634.

Rutten, M. E. J., Dore, A. G., & Halman, J. I. M. (2009). Innovation and interorganizational cooperation: A synthesis of literature. *Construction Innovation*, *9*(3), 285–297. https://doi.org/10.1108/14714170910973501

Saad, A. M., Dulaimi, M., & Zulu, S. L. (2023). Examining the influence of uk public clientsrsquo; characteristics on their own innovation-decision towards the modern methods of construction (mmc). *Sustainability*, *15*(5). https://doi.org/10.3390/su15054159

Sadin, S. R., Povinelli, F. P., & Rosen, R. (1989). The nasa technology push towards future space mission systems. In *Space and humanity* (pp. 73–77). Elsevier.

Sanchez, H., Robert, B., Bourgault, M., & Pellerin, R. (2009). Risk management applied to projects, programs, and portfolios. *International journal of managing projects in Business*, *2*(1), 14–35. https://doi.org/10.1108/17538370910930491

Saunders, M., Lewis, P., & Thornhill, A. (2009). *Research methods for business students*. Pearson education.

Sexton, M., & Barrett, P. (2003). A literature synthesis of innovation in small construction firms: Insights, ambiguities and questions. *Construction Management and Economics*, *21*(6), 613–622. https://doi.org/10.1080/0144619032000134147

Shehu, Z. (2008). *The framework for effective adoption and implementation of programme management within the uk construction industry* (Doctoral dissertation). Glasgow Caledonian University.

Shehu, Z., & Akintoye, A. (2009). Construction programme management theory and practice: Contextual and pragmatic approach. *International Journal of Project Management*, *27*, 703–716. https://doi.org/10.1016/j.ijproman.2009.02.005

Shehu, Z., & Akintoye, A. (2010). Major challenges to the successful implementation and practice of programme management in the construction environment: A critical analysis. *International Journal of Project Management*, *28*(1), 26–39. https://doi.org/https://doi.org/10.1016/j.ijproman.2009.02.004

Slaughter, E. S. (1998). Models of construction innovation. *Journal of Construction Engineering and Management*, *124*(3), 226–231. https://doi.org/10.1061/(ASCE)0733-9364(1998)124:3(226)

Spijkerboer, R., Busscher, T., Zuidema, C., Arts, E., & van Sandick, O. (2015). *Trends en opgaven in het ruimtelijk-fysieke domein*. Rijksuniversiteit Groningen. Faculteit Ruimtelijke Wetenschappen.

Thiry, M. (2002). Combining value and project management into an effective programme management model. *International Journal of Project Management*, *20*(3), 221–227. https://doi.org/https://doi.org/10.1016/S0263-7863(01)00072-2

Thiry, M. (2004). for dad: A programme management life-cycle process. *International Journal of Project Management*, *22*(3), 245–252. https://doi.org/https://doi.org/10.1016/S0263-7863(03)00064-4

Tromp, E., te Nijenhuis, A., & Knoeff, H. (2022). The dutch flood protection programme: Taking innovations to the next level. *Water*, *14*(9). https://doi.org/10.3390/w14091460

Trzeciak, M., Kopec, T. P., & Kwilinski, A. (2022). Constructs of project programme management supporting open innovation at the strategic level of the organisation. *Journal of Open Innovation: Technology, Market, and Complexity*, *8*(1), 58.

Turner, J. R., Turner, J. R., & Turner, T. (1999). The handbook of project-based management: Improving the processes for achieving strategic objectives.

Uyarra, E., Edler, J., Garcia-Estevez, J., Georghiou, L., & Yeow, J. (2014). Barriers to innovation through public procurement: A supplier perspective. *Technovation*, *34*(10), 631–645. https://doi.org/https://doi.org/10.1016/j.technovation.2014.04.003

Van Buuren, A., Buijs, J.-M., & Teisman, G. (2010). Program management and the creative art of coopetition: Dealing with potential tensions and synergies between spatial development projects. *International Journal of Project Management*, *28*(7), 672–682. https://doi.org/https://doi.org/10.1016/j.ijproman.2009.12.002

Van der Vlist, M., Roovers, G., & Barneveld, A. (2016). Vervangingsopgave natte kunstwerken in het hoofdwatersysteem en hoofdvaarwegennet in nederland. *Water Governance*, (2), 76–83.

Verschuren, P., & Doorewaard, H. (2010). *Designing a research project* (Vol. 2). De Hague: Eleven International Publishing.

Volker, L. (2019). *Just a little of that human touch: Towards a value-based ecosystem for delivering infrastructure services = gewoon een beetje meer menselijkheid: Richting op waarde gebaseerde ecosystemen voor het leveren van infrastructuurdiensten*. University of Twente.

Vosman, L. (2020). From project to programme: Drivers to a programmatic procurement approach in the dutch construction industry.

Vosman, L., Coenen, T. B. J., Volker, L., & Visscher, K. (2023). Collaboration and innovation beyond project boundaries: Exploring the potential of an ecosystem perspective in the infrastructure sector. *Construction Management and Economics*, *41*(6), 457–474. https://doi.org/10.1080/01446193.2023.2165695

Wamelink, J. W. F., & Heintz, J. L. (2014). Innovating for integration. In *Construction innovation* (pp. 149–164). https://doi.org/https://doi.org/10.1002/9781118655689.ch11

Wang, N., Xu, Z., & Liu, Z. (2023). Innovation in the construction sector: Bibliometric analysis and research agenda. *Journal of Engineering and Technology Management - JET-M*, *68*. https://doi.org/10.1016/j.jengtecman.2023.101747

Winch, G. (1998). Zephyrs of creative destruction: Understanding the management of innovation in construction. *Building Research Information*, *26*(5), 268–279. https://doi.org/10.1080/09613218369751

Xue, X., Zhang, R., Yang, R., & Dai, J. (2014). Innovation in construction: A critical review and future research. *International journal of innovation science*, *6*(2), 111–126.

Yan, H., Elzarka, H., Gao, C., Zhang, F., & Tang, W. (2019). Critical success criteria for programs in china: Construction companies perspectives. *Journal of Management in Engineering*, *35*, 04018048. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000659

Yin. (2009). *Case study research and applications: Design and methods* (Vol. 5). SAGE Publication.

A

Literature Review

This section describes a procedure for literature review based on input from Creswell (2014) and Verschuren and Doorewaard (2010).

1. Make a search plan using the variables and keywords
   The focus of this research is to examine the impact of innovation on infrastructure programme. To guide the research plan, two key variables are considered: Programme and Innovation. The utilization of a set of keywords is essential in locating relevant materials within academic article databases. The keywords for this research are categorized and presented in the following table

Table A.1: List of keywords related to programme

Group 1	Group 2	Group 3
Programme Management	Management	Infrastructure
Programme	Approach	Construction
Multi projects		Civil engineering
Project portfolio		Construction industry
Program		Construction company
Infrastructure programme		Megaprojects
		The Netherlands

Table A.2: List of keywords related to innovation

Group 1	Group 2	Group 3
Innovation	Management	Infrastructure
Innovation partnership	Public Procurement	Construction
Collaborative innovation	Procurement	Civil engineering
Management of innovations	Policy	Construction industry
	Barriers	Construction company
	Drivers	Megaprojects
	Motivations	Construction organisation
	Project	
	Process	
	Frameworks	

2. Apply the keywords to the article database
   For this research, research databases Google Scholar, Scopus, Science Direct, Research Gate, Elsevier, and Web of Science are used to search research papers and conference papers. In addition, a search is performed in TU Delft Repository to find a master thesis related to the research subject

3. Use the Boolean operators AND and OR to perform the search in the scientific database by using a combination of keywords identified in the table above. Make possible combinations or turn the order of the keywords in the groups seen in the tables above

4. Scan through the result of the search and read the caption of the search result. Skim through the initial group of articles if they are relevant to the research. The focus of this research is on programme in infrastructure but general articles about programme still be first considered due to the lack of availability of articles if just using very specific keywords in Group 3

5. Prioritize the relevant articles with high citation numbers avoid articles with low citation numbers and begin to read and review the articles

6. Use the snowballing principle once the researcher is satisfied with certain articles by reading the bibliography of the articles. A brief scan may give ideas or provide new keywords (Verschuren & Doorewaard, 2010)

7. Save the combination of search. Perform another round of search based on search combination and search history to find another set of articles if the first round of results is not satisfactory. This can be done in several rounds

8. Focus on the group of articles that were found based on the above criteria and retrieve the information needed for the research. Use the articles to answer the sub-research questions

B

Case Screening Procedure

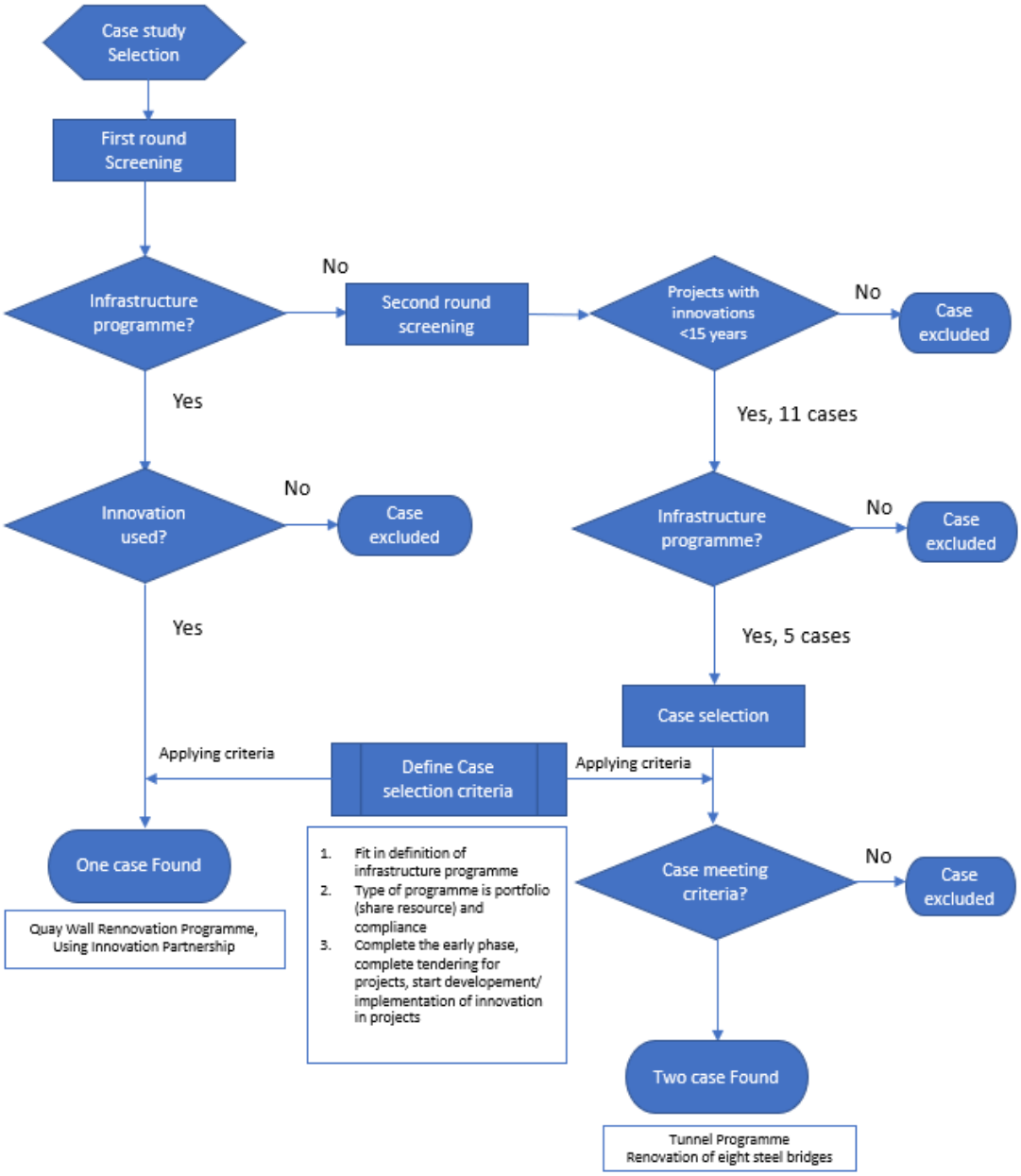

Figure B.1: Case screening procedure to identify case study (own figure)

C

List of documents reviewed

Table C.1: List of documents reviewed

Document code	Document Date	Document descriptions
IPQ1	2019	This document describes the renovation of quay wall projects, the innovation partnership process, scope and requirements of projects, risk sharing
IPQ2	2019	This document describes more detail the innovation partnership process and projects requirements
IPQ3	2020	This is the submission document where the initial proposal of innovation is presented to the clients. The working method of innovation is explained.
IPQ4	2020	Describes the proposed collaboration process during IPQ, innovation process and plan of development per TRL level
IPQ5	2023	This document describes the general progress of the programme and projects, budget cuts, and challanges of the programme until 2023
IPQ6	2023	Describes the process of IPQ-tender
IPQ7	2022	Describes the development of innovation in phase 2.1 (design phase), technical and process adjustments
IPQ8	2022	Describes the development of innovation in phase 2.1 (design phase), technical and process adjustments
IPQ9	2023	General programme information
IPQ10	2023	Presentation is given to describe a market strategy for the programme
IPQ11	2023	Illustration of programme organization from the municipality and relevance to companies
IPQ11	2020	Describe the progress of programme in Q2 2020
IPQ12	2020	Information about the programme update
IPQ13	2020	Information about market strategy
IPQ14	2018	Presentation to market parties about the intention of the Innovation partnership
IPQ15	2018	Initial presentation to market parties about the intention of the programme
RTR1	2019	This is the submission document for tender
RTR2	2021	This document describes the programme in general
RTR3	2020	Describes the success factors, enablers of innovations
RTR4	2018	Describes selection criteria for engineering service
RTR5	2023	Describe the development of innovations in programme, the impact of innovaitons
RTR6	2023	Describe the development of DTT innovations in tunnel programme
RTR7	2021	This document describes the programme in general
RTR8	2022	Showing the organisation responsible for the programme
RTR9	2021	This document describes the programme progress for 2021 in general
SBR1	2018	Describe the execution challenge of implementation of HPC, the collaboration factors, and briefly about the contract
SBR2	2012	This document explains the sequence of renovation, collaboration between client, MC, and contractors
SBR3	2017	This document mentioned the experience gain from of each bridges renovation (challanges and lessson learnt) in relation to HPC innovations
SBR4	2013	This documents describes contract requirements for the contractor to execute the design. It includes process and technical requirements of the bridge
SBR5	2017	Describing the challange and other innovation used in the SBR-project
SBR6	2009	Describe the barriers of design and implementation on Muiderbrug by one contractor combinations
SBR8	2022	Presentation by RWS about one of the bridge
SBR9	2009	Knowledge document from pilot projects

D

Semi structured interview

D.1. Email sent to interviewee

The following paragraph below was sent via email to the interviewees before the interview after the date of the interviews was determined. The email was sent together with the Informed Consent form that needs to be signed digitally or on paper.

Beste Dhr/Mvr,

Mijn naam is Savitri Dinar Wulandari. Ik ben een masterstudent Construction Management and Engineering (CME) van de TU Delft. Momenteel doe ik mijn afstudeeronderzoek bij Royal HaskoningDHV, op de afdeling Infrastructuur en Mobiliteit in Amsterdam, onder begeleiding van Petra Peters, Technische Manager en commissielid Dr.Ir. A (Ad) Straub (voorzitter), Dr.Ir. M (Maedeh) Molaei (eerste supervisor), en Dr. E. J. (Erik-Jan) Houwing (tweede supervisor). Ik neem contact met u op in verband met mijn afstudeeronderzoek en ik heb xxx Programma als casestudy gekozen.

Het doel van dit onderzoek is het onderzoeken van de implementatie van innovatie door bedrijven in een multi-project setting als onderdeel van infrastructuurprogramma, waarbij de nadruk ligt op de relatie tussen het innovatieproces, belemmeringen en stimulerende factoren van innovatie, en de aanpak van het bedrijf voor innovatie binnen de programmacontext. Om dit te bereiken wil ik een interview van 60 minuten met u afnemen, waarin ik open vragen zal stellen om uw perspectieven op het onderwerp te verzamelen. De verzamelde gegevens zullen worden gebruikt om verbanden te leggen tussen de implementatie van innovatie binnen het infrastructuurprogramma en aanbevelingen te doen voor de aanpak van het bedrijf om bij te dragen aan het algemene doel van het programma.

Het interview zal worden opgenomen om de transcriptie te vergemakkelijken, en er zal alles aan worden gedaan om de vertrouwelijkheid van uw antwoorden te waarborgen, waarbij persoonlijke gegevens zullen worden geanonimiseerd. De persoonlijke gegevens (naam, e-mailadres, beroep) worden alleen verzameld voor scriptiegerelateerde doeleinden. Alle gegevens van dit onderzoek, inclusief de persoonlijke informatie, audio, en de transcriptie zullen veilig worden opgeslagen binnen de TU Delft omgeving (TU Delft project drive). Deze gegevens zijn alleen beschikbaar voor de thesis supervisor van de TU Delft en worden nergens gepubliceerd. Wij wijzen u erop dat wij weliswaar maatregelen zullen nemen om het risico van datalekken te minimaliseren, maar dat dergelijke risico's bij online activiteiten niet volledig kunnen worden uitgesloten.

Als u aan dit onderzoek wilt deelnemen, plan ik graag een interview met u in. Deelname aan dit onderzoek is geheel vrijwillig, en u kunt ervoor kiezen geen vragen te beantwoorden tijdens het interview als u dat wilt. Graag contact met mij op te nemen als u meer informatie wenst over dit onderzoek.

Met vriendelijke groet,

D.2. Interview protocol

The interviews are conducted in six parts. The first part is an introduction of the researcher and interviewees. Second, part II focused on basic information and a general understanding of the programme, innovation, and the relation of innovation in the infrastructure programme context. Part III dives into barriers identification and their related issue in practice. Part IV focuses on the interviewees' opinions on the enablers for innovation in programme. In Part V, interviewees are asked about the impact and preconditions of the programme, and Part VI concludes the interview. A set of questions for interviewees from RHHDV, partners (engineering company and contractor), and contractor is prepared per part including the backup questions. For parts II and III, follow-up questions are asked based on the answers of the interviewees.

The interviews are conducted in Dutch, therefore, the interview protocol below is presented in Dutch.

Deel I - Inleiding (5min)

- Inleiding over de onderzoeker
  Voor begin het interview, zullen we even kort voorstellen voor de opname?
  Mijn naam is Savitri Dinar Wulandari, Indonesische masterstudent van de TU Delft. Ik zit momenteel in het tweede jaar van mijn studie Construction Management and Engineering en doe ik onderzoek hier bij RHDHV onder begeleiding van Petra Peters. Mijn onderzoek gaat over het verkennen van de mogelijkheden van innovatie in het infrastructuurprogramma. Kunt u zelf voorstellen? Wat is uw functie in het bedrijf en wat is uw ervaring met het werken met programma?

- Het doel van dit onderzoek is om kennis te vergaren over de implementatie van innovatie in de multi-project setting als onderdeel van het infrastructuurprogramma en om meer inzicht te krijgen in de factoren en mechanismen die een cruciale rol spelen bij de verdere ontwikkeling en implementatie van innovatie in het infrastructuurprogramma. Dit omvat hoe de innovatie in de multiprojectomgeving wordt genitieerd, het mechanisme om de innovatie voor te stellen en de rol van de bedrijven en hun partners/supply chain in het innovatieproces.
  Dit interview heeft tot doel de belemmeringen en stimulansen voor innovatie in multiprojecten in het kader van infrastructuurprogramma's in de praktijk te identificeren, die later zullen worden vergeleken met die op basis van theoretische achtergronden. Daarnaast zal de huidige strategie voor de implementatie van innovatie in projecten worden besproken

- Als het staat binnen de inform consent formulier dat ik eerder gestuurd heb, zal dit interview in audio opgenomen worden en tot een tekst verwerken.

- Dit interview bestaat uit zes delen. Het begint met deze introductie and Deel II gaat over de basis informatie en algemeeen begrip. In Deel III ga ik vragen over de belemmeringen en bijbehorende thema. Vervogens, ga ik in Deel IV vragen over de stimulerende factoren (enablers). In deel V vraag ik over impact en randvoorwaarden van de programma voor we eindelijk de interview afsluiten in Deel VI.

Deel II - Basisinformatie en algemeen begrip (10min)

1. Hoe definieert u een infrastructuurprogramma?
2. Wat is uw definitie van innovatie in de infrastructuursector?
3. In het algemen, draagt de innovatie bij aan het programma? Zo ja, waarom?
4. Wat zijn de motivaties om mee te doen in RTP/RQW/SBR?

Deel III Belemmerigen en bijbehorende themas(15min)

1. Wat zijn volgens u de belemmeringen voor de ontwikkeling/implementatie van innovatie in programma zoals RTP/RQW/SBR? Kunt u onderscheid maken op basis van de fase van de projecten/programma's? (notitie for interviewer: als indicatie kan dit in hetbied van financieel,

regelgeving, organisatie, samenwerking, sectoraal or andere factoren zijn, indicatie phase in case case RQW: ontwerpfase, proeffase; RTP: ontwerpfase, SBR:afronding HSB maar het programma loopt nog).

2. Zouden deze belemmeringen anders zijn als het om een enkel project/geen programma gaat? Wat zijn de reden?
3. Wat zijn volgens u de oplossingen voor die belemmeringen?

Gebaseerd van aantwoord van vraag 1, kies vraag 4- 7

4. Samenwerking
    - Hoe helpt de aanbestedingsregels deze innovatie om makkelijker te gebruiken in de programma context (of multi projecten)?
    - Zou deze aanbestedingsvorm volgens u de langdurige samenwerking met de opdrachtgevers stimuleren?
    - Hoe is de samenwerking tussen jullie en opdrachtsgever/ andere partners?
    - Hoe ziet u een flexibiliteitselement in dit programma?
5. Financieel aspecten
    - Wat is de meest dominante financile belemmering voor de ontwikkeling en/of implementatie van innovatie in dit programma? (Bekend: hoge kosten, lange terugverdientijd, gebrek aan winstgevendheid, nauw verbonden met beperkte schaalgrootte, onvoldoende volume en gebrek aan continuteit vanwege het tijdelijke karakter van projecten)
    - Hoe loss u dit probleem op intern en met opdrachtgever?
    - Hoe is het resico verdeling? In welke mate denkt u dat het verdelingsmechanisme (het risico) in dit contract werkt?
6. Cultureel aspecten
    - Wat is de invloed van de bundeling van de projecten op de kennisuitwisseling?
    - Vindt u dat RHDHV als bedrijf voldoende netwerk heeft? Of ja, in welke mate is de invloed van de netwerk naar innovatie ontwikkeling?
    - Zoals ik begreep heeft RHDHV een innovatieprogramma, wat is uw mening daarover?
7. Sectoral
    - Wat is de betrokkenheid van de opdrachtgever in de projecten? Wat zijn actieve rollen van de programma organisatie?
    - Is er volgens u voldoende vraag naar innovatie vanuit de oprdachtsgevers?
    - Hoe helpt de betrokkenheid van clinten bij de uitvoering van het programma?
    - Hoe benvloedt het budget voor innovatie in dit project de uitvoering?
    - In het project RQW/RTP/SBR heeft RHDHV samen met uw partners innovaties ontwikkeld en/of geimplementeerd. Wat is de betrokkenheid van de opdrachtgever in dit proces?

Deel IV - Stimulerende factoren en bijbehorende thema (15 min)

1. Nu de belemmeringen in kaart zijn gebracht, wat zijn volgens u de factoren die innovatie in dit project mogelijk maken?

Gebaseerd van aantwoord van vraag 1, kies vraag 2- 5

2. Cultureel
    - Op basis van informatie in innovation's hub (interne innovatiewebsite van RHDHV) is de externe focus van RHDHV het verbreden van het dienstenportfolio en het genereren van meer inkomsten. Is de implementatie van innovatie in dit project volgens u in lijn met de bedrijfsfocus?
    - Op welke manier stimuleert/bevordert RHDHV innovatie in het project? Zal het anders zijn als het om een enkel project of een programma gaat?

- Denkt u dat jullie bedrijf voldoende capaciteit heeft om te innoveren?
- Wat is de invloed van het netwerk van het bedrijf en de toeleveringsketen op de innovatie?
- Hoe ziet u de invloed van het leiderschap van de klant op de innovatie?

3. Samenwerking

   - Wat zij de belangrijke samenwerking factoren in deze projecten?
   - Welke factor acht u cruciaal in deze contractvorm?
   - Wat zijn de motivatie om innovatie toe te passen in deze programma?
   - Met de huidige manier in samenwerking en aangezien vaan de voortgang van de projecten, kan de opdrachtsgevers zijn doelen voot het programma bereiken?

4. Financieel

   - In welke mate motiveert de stimuleringsregeling bij de huidige contractvorm het bedrijf om te motiveren?
   - Wat zouden mogelijke andere financile motivaties zijn om te innoveren in de multiprojecten?
   - Wat zijn jullie visie voor deze innovatie?

5. Sectoral

   - Wat is de invloed van uw netwerk op de ontwikkeling van innovatie in deze projecten?

Deel V Impact en randvoorwaarden

1. In u mening, wat zijn de randvoorwaarden voor het voorstellen en uitvoeren van innovatie in de multiprojecten binnen het programma?
2. Op welke wijze denkt u dat de marktpartijen het programma kunnen benvloeden?
3. Wat is volgens u de optimale manier om de continuteit van de innovatie in het programma te waarborgen?
4. Wat zijn volgens u de effecten van de bundeling van de projecten binnen het programma op de implementatie van innovatie? (In het kader van samenwerking en netwerk, contractueel, leren) op: (a) projectprestaties/programmaprestaties en b) organisatieprestaties?
5. (Back-up vraag) Hypothetisch gezien, wat zijn er andere (betere) manieren voor de opdrachtsgever om deze zoort projecten te organiseren?

Deel VI Afsluiting

1. Zijn er nog andere punten van zorg in verband met de uitvoering van het innovatieprogramma?
2. Korte conclusie en transcriptie van het interview zullen aan de genterviewde worden gestuurd

E

Coding for Atlas.ti

Codes are created based on the identified aspects by using deductive methods. For example, codes related to barriers are created and further broken down into keywords. The utilization of keywords played a crucial role in identifying relevant quotes and getting deeper insights into valuable information within the collected data.

The coded interviews are also categorized into themes to help organize the data. Themes reflect the interconnection between codes. These themes are generated from the literature studies or commonalities in the text. This process is iterative, therefore there is a possibility that new codes and themes will be created based on the transcripts of the interviews. This iterative process is undertaken to ensure the analysis is comprehensive and yields a clear, accurate, and unambiguous interpretation of the data before finally capturing the essence of the research question.

Table E.1: List of documents reviewed

Category	Theme	Code	Keywords
1. Barriers	Contract and Regulation-related barriers	Contract breech, Contract form barrier, Contract not used to full extend, Procurement procedure, Scope and/or requirements	Tender, contract, technical requirements, functional requirements, long tender phase, framework agreement, mini-tenders, competition, interpretation
	Financial-related barriers	Innovation cost, difficulty to internalize benefit, rigid financial plan	Financial, economic, rewards, risk-sharing, uncertainty, scale-up, multiplication, continuity, predictability, future works, (high) cost, expensive, price, investment, uncertainty, budget, return on investment, profit margin
	Knowledge exchange-related barriers	Knowledge exchange external, knowledge exchange internal	Knowledge exchange, learning, sharing, lessons, network, competitions, sharing session, learning session, changing in team
	Market-related barriers	Market-related barriers	Competition, competitive, advantage, trend, tendency, market situation, ambitions, continuity, price, requirement, common practice
	Client-related barriers	Client commitment, organization demand, organization size, conflict between goal and other requirements, risk-averse behavior	Commitment, stakeholders, internal stakeholders, groups, interest, demand, unclear demand, unclear offer, unclear request, organization structure, organization size, big organization, decision process, risk-taking, risk-averse, separate organization, programme organization, politic, influence, agreement
	Collaboration and cultural-related	Contractual procedure, lack of trust, stakeholder acceptance, collaboration effort negative	Acceptance, stakeholders, against, not ready, lack of trust, way of working, the same way, traditional, violating agreement, distance, problem-solving, discussion, meetings, informal, formal, open communications, regulations, rules, honest, mindset, mandatory, relationship, dynamic, change on team
	Technical-related barriers	Technical challenge	Method, technically challenging, continuous adjustment, uncertainty, unknown technique, complex, large scale, experience, R&D, knowledge, technical resources, common practice, trial and error
	Time-related barriers	Time	Time, longer duration, extensive period

2. Enablers	Contract and Regulation and procedure-related enabler	Contract form, contract clarity, contract form	Innovation encouraging procurement, rewards, incentives, flexibility, space to innovate, Clear risk sharing, black and white, contract responsibility, intellectual property
	Collaboration and cultural-related enablers	Collaboration effort positive, informal, contractual, leadership, network influence	Partnering, long-term collaboration, trust, coordination, communication, open communication, formal, informal, known partner, network, motivations, problem-solving mechanism, solution, continuity, ambitions, discussion, solution, active participation, relationship, flexible, meeting, goals, organization, teamwork, organization culture,w ayr of working
	Client-related enablers	The clear role, clear vision, and ambitions	Leadership, client influence, ambition, vision, intention, organization, function, leader, clear demand, managers
	Knowledge exchange-related enablers	Knowledge exchange internal and external	Improvement, continuity, optimization, willingness to learn, sharing, knowledge sharing, lesson learnt, sharing sessions, evaluation session, discussion, transfer knowledge, suggestions, solutions, learning curve
	Financial-related enablers	Clear financial benefit, solid business case, innovation budget	Business case, invest, return of investment, (dedicated) budget, certainty of works/projects, profit margin, investment, earning, agreement on budget, reimbursement, incentive
3. Pre-conditions	Pre-conditions	Pre-conditions	Partnering, procurement, regulation, clients capability, capacity, trust, collaboration, alignment, strategy, joint performance, shared goals, suitable partner, ambitions, long-term collaboration, budget, investment, knowledge, learning, resource capacity

F

Case Study Analysis

This appendix presents the document review of each case study.

F.1. QWR document review

Characteristics of BQWP

The Municipality of Amsterdam initiated BQWP to swiftly renovate deteriorating bridges and walls over several years, ensuring safe infrastructure [IPQ11]. Conventional methods of renovations would span a century, causing ongoing disruptions and high costs (Amsterdam, 2022). The complexity of the renovation works is contributed by the limited workspace from the land side, therefore the works must be executed and material should be transported from the waterside [IPQ15]. Innovation is therefore needed to reach the desired efficiency and effectiveness [IPQ9]. This further serves as a secondary goal of this programme.

BQWP, centrally organized by the Municipality of Amsterdam, encompasses various projects including quay wall renovations (QWR) and bridge renewals, designed for synergies and circularity. Projects run concurrently and sequentially, such as traditional quay wall renovation alongside innovation development within the Innovation Partnership quay wall (IPQ). An illustration of BQWP can be seen in Figure F.1. Under the IPQ, three combinations of market parties are currently working to develop innovations that are going to be used for sequential quay wall renovation works [IPQ9]. The focus of this case lies in the IPQ, where the Konigsgracht combination is one of the market combinations working on innovations.

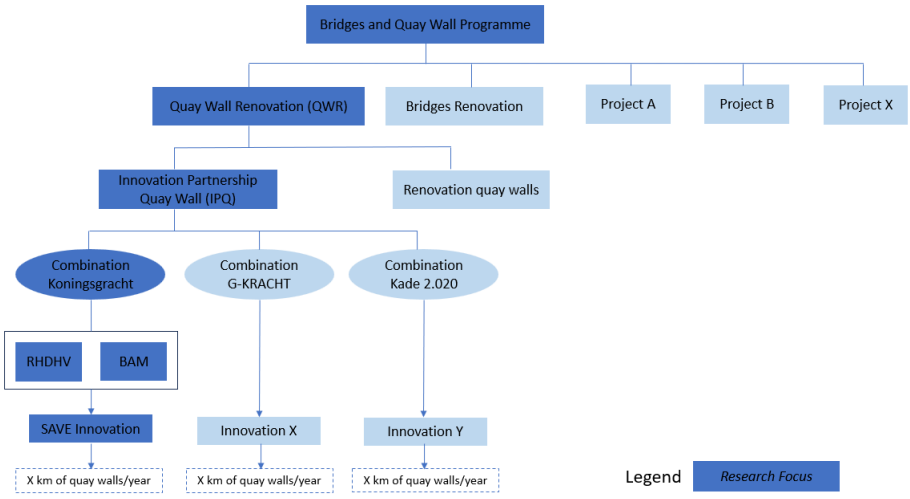

Figure F.1: Overview of Bridges and Quay Wall Programme (own figure)

Various teams under programme director are created to ensure smooth preparation and execution of projects under BQWP. Figure F.2 below indicates how the programme organization of clients correlates

with the contractors and how communication lines are formed between positions in both organizations. For example, the contract team from clients has a dedicated contract manager for each IPQ contractor's combination [IPQ9].

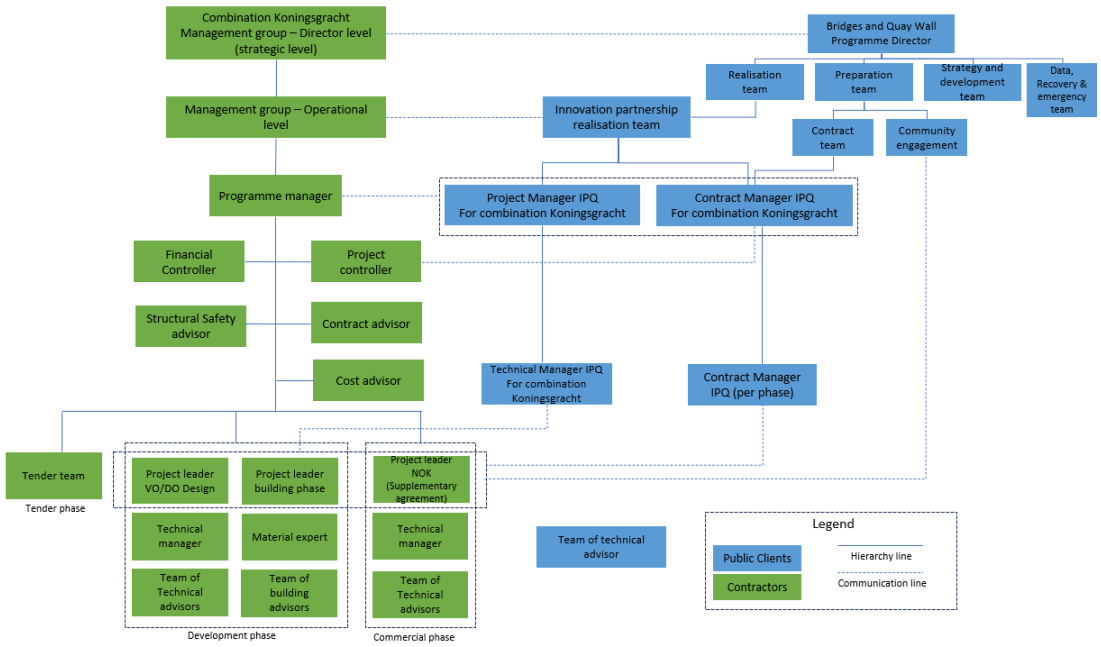

Figure F.2: Programme organization in relevance with company's project organization (own figure)

Given the historical city center's public space renovations, external stakeholders (citizens, floating house residents) and internal (traffic, public space, monumental, water network teams) are pivotal in BQWP complexity [IPQ1, IPQ10]. As seen in Figure F.2, a dedicated team oversees stakeholders in tandem with contractors [IPQ9]. Contractors also manage stakeholder needs [IPQ2]. Stakeholders' involvement, from innovation development to implementation, is integral per IPQ tender specs [IPQ1].

Projects within BQWP demand coopetition among market parties. To facilitate competition, the municipality fosters a market community of 170 members from 26 market entities, encouraging communication and knowledge exchange on program advancement. This encompasses both companies and knowledge institutions [IPQ12].

Innovation process in QWR

In the search for new methods, the Municipality of Amsterdam employs the Innovation Partnership Quay Wall (IPQ) in collaboration with selected market participants. IPQ's primary objective is to accelerate city center quay wall restoration [IPQ1]. Four project goals derive from this: minimal disruption, quick execution, wide applicability, and cost-efficiency [IPQ1], aiming for a 50% improvement in current renovation standards. Additional goals include sustainability, multifunctionality, and innovation stimulation, reflecting municipal aspirations [IPQ1]. These objectives drive IPQ's innovation development and implementation.

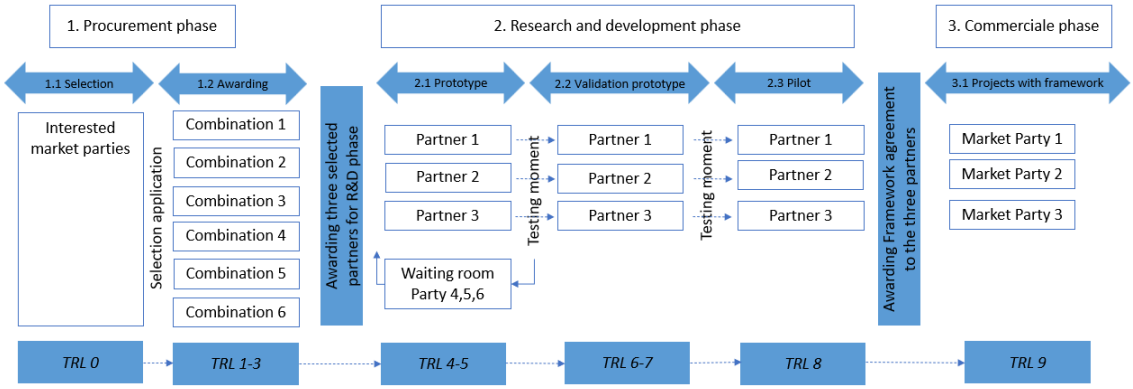

Figure F.3: Steps in Innovation Partnership Quay Walls [IPQ6] (own figure)

Innovation partnership quay wall (IPQ) is performed in four major steps as depicted in Figure F.3. The process involves market consultations for interest and feedback, followed by partner selection and the research and development phase (R&D). Successful pilots lead to a commercial phase. The three chosen partners under IPQ gain a framework agreement for innovation-based quay wall renovation without tendering, reducing competition. IPQ's pilot phase tests innovations across three sites [IPQ]. The Koningsgracht combination (RHDHV and BAM) develops SAVE innovation, chosen for scalability, minimal impact, and faster, sustainable methods [QWR5]. From a technical standpoint, the current methods are not future-proof and fail to ensure the long-term stability of the quay. As depicted in Figure F.1 below, the Municipality has other projects that run in parallel with IPQ where innovations are possibly used [IPQ9].

During the procurement, Koningsgracht combinations advanced SAVE innovation from TRL 0 to TRL 3. Following the Innovation Partnership agreement, further development spans TRL 4 to TRL 8 in three phases (Figure F.3). TRL 8 signifies successful pilot validation of innovation, fully operational for quay wall renovation before commercialization [IPQ4]. In Phase 2.3, SAVE must meet IPQ agreement's validation and verification criteria [IPQ4].

SAVE innovation combines known methods/technologies with novel adaptations for quay wall renovation in Amsterdam, requiring new techniques and proof of application [IPQ3]. Unique in the Netherlands and worldwide, SAVE integrates product and process innovation, a radical approach to quay wall renewal. The R&D for SAVE involves: (1) small electric pontoons for water-based work, (2) constructive design of the quay wall, (3) process development which includes advanced design software, 4) new execution processes including faster permits, and 5) sustainable, circular materials [IPQ3]. SAVE aims for quicker, safer, less disruptive, and century-long sustainability, aligning with program objectives [IPQ3]. When SAVE innovation is implemented, the renovation is expected to be faster, safer, less hindrance to the surroundings, and sustained for 100 years. In this. IPQ budget derives from programme's budget, factoring schedule, risks, and costs [IPQ5]. During tendering, detailed budgets cover materials, labor, phases, and costs, ultimately reimbursed by public clients per partnership agreements [IPQ2]. Following full validation in phase 2.3, company earnings link to the agreed price per renovated quay wall kilometer [IPQ2].

F.2. RTR document review

Characteristics of RTR

The Amsterdam Road Tunnels Renovation (RTR) Program aims to upgrade and enhance three major tunnels owned by the Municipality of Amsterdam. Goals include prompt compliance with tunnel regulations for safety and availability, as well as creating uniform operation and future-proof equipment [RTR2]. The municipality decided to bundle the tunnel renovation projects in a programmatic approach not only to address the urgency of complying with tunnel safety requirements but also to generate additional value through the synergies achieved by combining the projects. This approach minimizes traffic

disruptions, assures unified tunnel system control, and spans 2018-2028 for a comprehensive overhaul [RTR7]. A dedicated budget supports RTR's realization [RTR7].

The RTR programme consists of three road tunnel renovation projects and a traffic control center [RTR2, RTR7]. The overview of the RTR programme can be seen in Figure F.4. Two of the tunnel renovations were completed in 2022 and these become the focus of this research. Further explanation will be given in the next section.

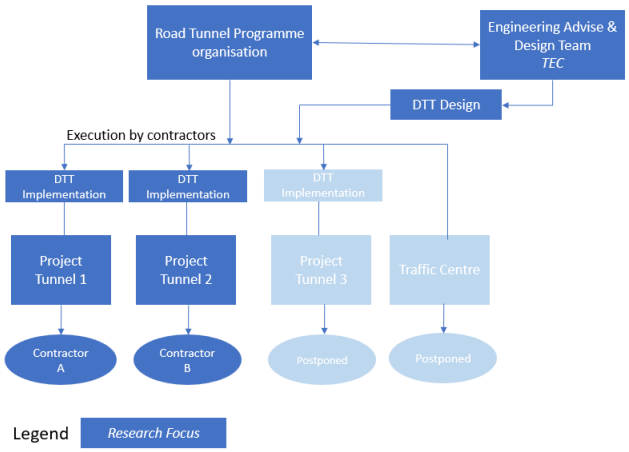

Figure F.4: Overview of Road Tunnels Renovation Programme (own figure)

As per the Q3 2021 report, third tunnel execution and traffic control center projects are postponed, despite the urgent need for third tunnel renovation [RTR7]. RTR is organized in a sequential manner by the Metro and Tram service organization of Amsterdam Municipality, part of the Directorate of Traffic and Public Space for accelerated learning across projects [RTR8]. The knowledge and expertise gained from one project can be immediately applied to subsequent projects, enhancing the overall efficiency of the program [RTR1]. Each project scope and plan are drawn individually under the RTP to achieve the project objective that contributes to the overall programme goals.

The program aims for tunnel system uniformity and integration, emphasizing standardization for simplified maintenance [RTR7]. BIM and Digital Twin Technology (DTT) are key, used for tunnel operations, testing, training, and driving innovation. The realization of DTT in RTR is organized at the programme level to ensure uniformity and integrity between projects and efficiency in the development was reached [RTR3]. BIM and DTT interlink projects, enhancing planning, quality, and cost [RTR3]. In addition, the utilization of BIM and DTT is also aligned with the tunnel management organization's vision as an intended operational management in 2030 [RTR7].

Stakeholders, vital in RTP, are strategic partners: Tunnel Authority, traffic management, safety officers, city officials, and environmental service. Other stakeholders, including citizens, users, and internal and political stakeholders, are managed separately within RTP [RTP2].

Innovation process in RTR

The Tunnel Engineering Consultant (TEC), formed by RHDHV and Witteveen+Bos, secured a four-year framework agreement for technical consultancy in the RTR program [RTP3]. To ensure consistency, knowledge development, and collaboration, the municipality chose a single party for the entire program [RTR4]. TEC partnered with Infranea for BIM, 3D designs, and Digital Twin Development (Infranea, 2019). Integrated design aids program alignment and includes DTT, user integration, procedures, and technical installations [RTP3].

During the commissioning phase, it is imperative that the delivered system meets specific requirements

and intended use. The tunnel system, in line with the program's goals, should be user-friendly, easily operable, and maintainable. This necessitates not only proven technological solutions but also established processes and procedures that are comprehensible to the users. Users must receive training and practical experience with the new standardized system to effectively operate and maintain the tunnels [RTP3]. An alliance with Contractor A (indicated in Figure F.5) and a two-phase contract with Contractor B expedited DTT implementation in Tunnel 1 and 2 renovations [R1RTR, R2RTR]. This form of collaboration allows TEC as the advisor and designer of DTT to work closely with the contractors [R1RTR, R2RTR].

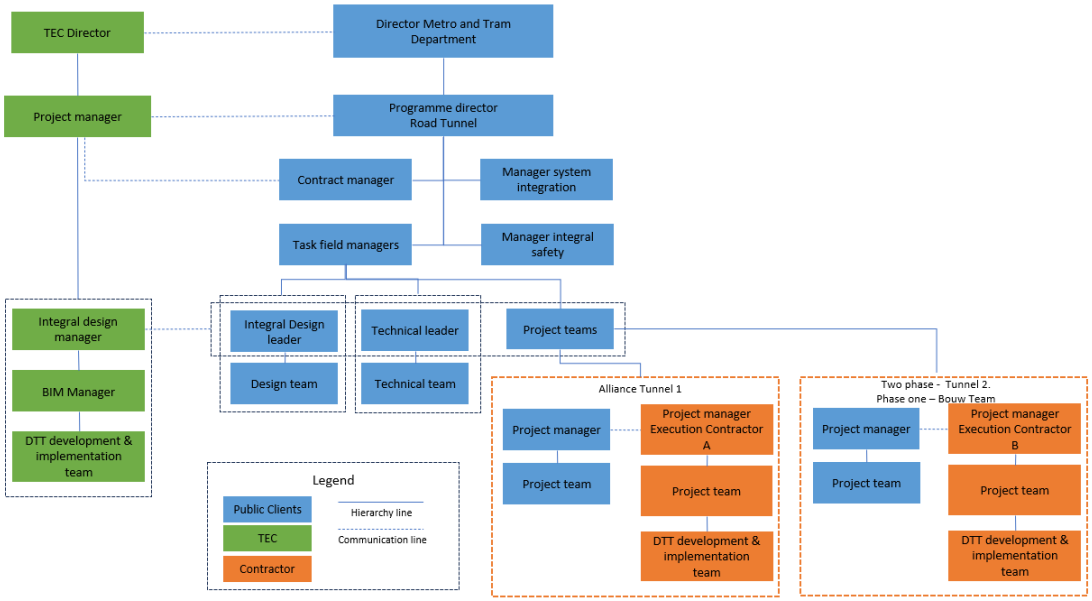

Figure F.5: Programme organization in relevance with company's project organization (own figure)

A digital twin is a virtual version of a physical asset, allowing non-disruptive testing, simulation, and training. Integrating BIM, the Internet of Things (IoT), and Virtual Reality (VR), it's a novel approach to tunnel engineering [RTR3]. TEC's prior experience in tunnels, on a smaller scale, led to RTR's large-scale DTT application, categorized at TRL 7-8. DTT mitigates risks, accelerating program objectives [RTR3]. DTT's functionalities include early design validation, digital testing, and training, enhancing safety, reducing failure costs, and minimizing the lead time for better tunnel availability [RTR3].

F.3. SBR document review

Characteristics of SBR

Rijkswaterstaat (RWS), as the owner of infrastructure assets, including bridges in the Netherlands, is confronted with a significant challenge concerning its steel bridges. These bridges, constructed primarily during the 1960s and 1970s, were built using methods prevalent during that time and are now nearing the end of their intended lifespan. Fatigue-related damage to the structure poses a long-term risk to these bridges, particularly evident in the bridge deck. The deterioration not only reduces the expected lifespan of the bridges but is further exacerbated by the increasing traffic volume, particularly for bridges situated in the primary road network [SBR3]. High-Performance Concrete (HPC) is a solution, reinforcing decks to extend lifespan by 30 years. Eight steel bridges in the main road network underwent a consolidated renovation under the Replacement and Renovation Programme, leveraging HPC technology and knowledge [SBR3].

To execute this, RWS contracted RHDHV, Arup, and Greiss as the Managing Contractor (MC) for HPC design and bridge renovation [SBR1]. The MC contract, an innovative approach, included renovation design and aiding renovation execution tender [SBR2]. Given that High-Performance Concrete (HPC)

was a relatively new innovation, contractors were not yet acquainted with its working methods. Therefore, the decision to bundle the projects was also intended to serve as a learning opportunity for market participants, which could be applied to future steel bridge renovations throughout the Netherlands. These projects allowed the MC and contractors to develop and enhance their renovation techniques. A combination of three contractors was specifically chosen to undertake the SBR project. The overview of the SBR can be seen in Figure F.6 below where eight steel bridges are assigned to SBR as a mini-program.

The implementation of HPC on the bridges was carried out in three distinct phases.

1. Phase 1 (2009 2011) Muidenbrug, Beekbrug, Scharbergbrug
2. Phase 2 (2013- 2017) Gallecopenbrug, Ewijk, Kreekrakbrug
3. Phase 3 (2017 2028) Suurhoff, Van Brienenoordbrug

In reality, the HPC innovation only applied to six bridges due to the technical limitation that has been reached [SBR3]. The six bridges have been delivered in 2017. Bridge 7 was also not utilizing HPC and instead of renovation, a new bridge was placed. At the moment, Bridge 8 is still in the tender process for replacement works (Rijkswaterstaats, 2023a). In short, SBR is considered an extremely long-term programme, that has been ongoing for fourteen years and counting.

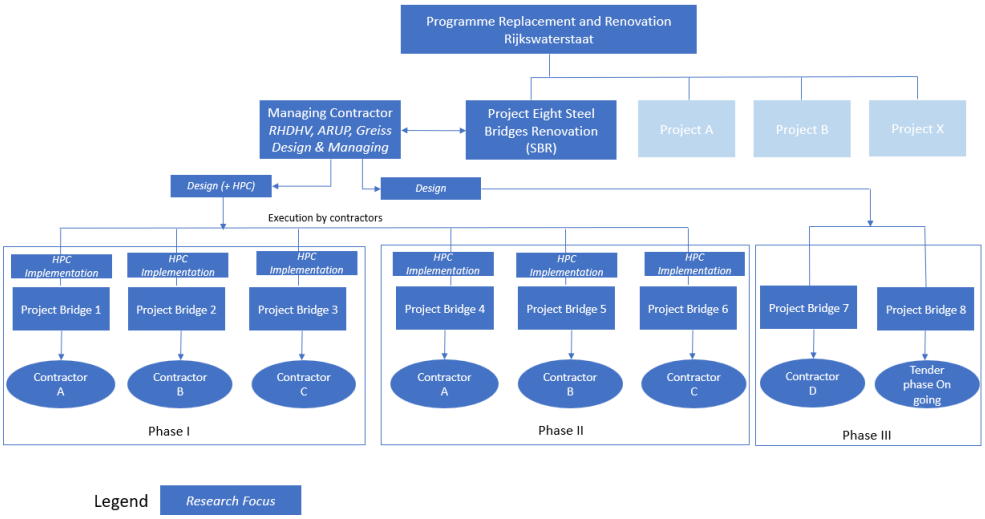

Figure F.6: Overview of Eight Steel Bridge Renovation Programme (own figure)

To execute the renovation work, three contractor combinations were contracted under a framework agreement to perform the renovation work and the necessary reinforcement under the condition that the HPC was implemented in the renovation works [SBR3]. Before acquiring a project, a contractor combination must undergo a tender process (within the framework agreement) and compete with two other combinations [SBR1]. The programme organization seen in Figure F.7 below illustrates the relations between RWS as a client, Managing Contractor, and an example of contractor project organization in one bridge project. On the client side, the project manager for SBR was appointed and reported to the programme manager. Under the project manager, a contract manager per bridge was assigned. This function was a combined function of the project manager and contract manager [SBR1]. In addition, a community engagement manager was also assigned per bridge. On the MC and contractors' side, project organizations mirrored each other, although the size of the organization may differ. The functions on the diagram shall be present on every bridge project.

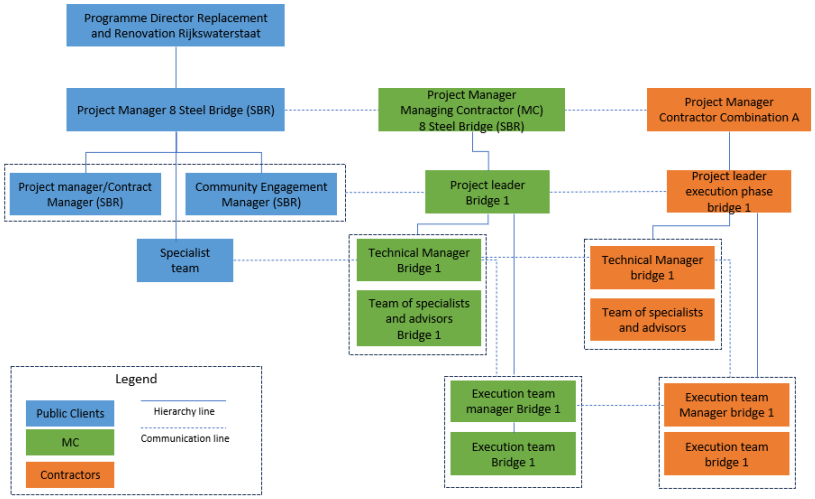

Figure F.7: Programme organization SBR in relevance with company's project organization (own figure)

SBR is a group of multi-project that is not an official programme itself, but it is instead a part of the national wide Replacement and Renovation programme of RWS. However, based on the literature study, SBR has the character of a programme, therefore it is considered a study case in this research.

Innovation process in SBR
Prior to its implementation on multiple bridges, RWS conducted pilot tests on the Calandbrug Bridge and Moerdijkbrug Bridge in collaboration with several contractors to test the relative novelty and technical complexity of implementing HPC [SBR9]. As it has been mentioned in the previous section, following a positive result of the HPC application on the pilot projects, the decision was made to apply HPC in steel bridges where eight bridges were identified. The decision to execute the renovation in three phases is partially based on technical urgency and the increasing complexity of the bridge. Despite the successful outcomes of the pilot tests, the application of HPC still requires careful implementation and monitoring for each bridge. As a result, these renovation projects are complex and extensive in nature. From the theoretical perspective, when the SBR started, it was considered a substantial innovation, where the TRL level was 7-8.

As indicated in Figure F.6, the renovation was done in there phases. The first three bridges must be renovated at the earliest, and they are considered less complex compared to the other bridges. In the first phase, the application of HPC on the three bridges was simultaneously conducted by a combination of three contractors. The design and execution of these bridges required extensive work due to the uniqueness of every bridge and HPC could not just be straight away applied on each bridge [SBR1]. The knowledge gained from this first phase was then applied to the second phase, where the design was optimized, and the scope of the renovation was expanded. The cumulative experience and learning from the first and second phases were then utilized in the third phase. Phasing the renovation is chosen to ensure the lessons from one phase renovation, such as bridge characteristics, renovation scope, recalculations, and HPC implementation, were transferred from one project to another [SRB3]. A significant insight derived from this series of bridge renovations is that relying solely on pre-assumed conditions in renovation projects is unreliable. Therefore, the implementation of HPC innovation should be approached in a flexible manner. The projects revealed previously unknown factors associated with implementing innovation, and valuable experience was gained throughout the process [SBR3].

G

Findings barriers and enablers from the interviews

The following tables indicate all responses from the interviewees for the barriers and enablers to innovations

Table G.1: Summary of barriers found in case study

No.	Barriers	R1RTP	R2RTP	R1QWR	R2QWR	R1SBR	R2SBR	R3SBR	P1RTP	P1QWR	C1SBR	C2SBR	Total
1	Technical challenge	X	X		X	X	X	X	X	X	X		9/11
2	Contract form		X	X	X		X			X	X	X	7/11
3	Innovation cost	X	X		X	X				X	X	X	7/11
4	Client organisational size/structure		X	X	X		X		X	X		X	7/11
5	Knowledge exchange barrier with external parties					X	X	X	X		X	X	6/11
6	Time barrier				X	X	X			X	X	X	6/11
7	Client organisation demand			X	X		X		X	X		X	6/11
8	Scope and/or requirements			X	X	X	X			X			5/11
9	Stakeholders acceptance	X	X		X				X				4/11
10	Conflict between goals and requirements			X					X	X			3/11
11	Knowledge exchange barrier with internal parties						X				X		3/11
12	Contractual procedure			X			X			X			3/11
13	Collaboration effort negative			X		X							3/11
14	Risk adverse behaviour			X								X	3/11
15	Difficult to internalize benefit				x					X		X	3/11
16	Procurement procedure			X						X			3/11
17	Market barrier			X							X	X	3/11
18	Lack of trust									X		X	3/11
19	Client commitment									X		X	3/11
20	Financial not flexible									X			3/11
21	Contract breech									X			3/11
22	Contract not used to full extend										X	X	3/11
23	Cultural barrier									X			3/11

Table G.2: Summary of enablers found in case study

No	Enablers	R1RTP	R2RTP	R1QWR	R2QWR	R1SBR	R2SBR	R3SBR	P1RTP	P1QWR	C1SBR	C2SBR	Total
1	Contract form	X	X	X	X	X	X	X	X	X	X	X	11/11
2	Collaborative effort positive	X	X	X	X		X	X	X	X	X	X	10/11
3	Knowledge exchange with external parties	X	X	X	X	X	X	X		X	X	X	10/11
4	Network influence	X	X		X	X	X		X	X	X	X	9/11
5	Knowledge exchange with internal parties			X	X	X	X	X	X	X	X	X	9/11
6	Clear vision and ambition	X	X			X	X		X				5/11
7	Leadership	X	X				X	X				X	5/11
8	Solid business case	X						X	X	X	X		5/11
9	Financial Innovation budget	X				X			X	X			4/11
10	Contract clarity					X				X	X		3/11
11	Contractual		X				X	X					3/11
12	Client related - Clear role									X			1/11
13	Informal collaboration				X								1/11
14	Contract duration								X				1/11
15	Clear financial benefits										X		1/11

H

Initial Framework

Part I - Establish foundation for innovations in programme				
Programme/project Initiations	**Programme /project definition**	**Programme/project implementation**		**Programme/project Dissolution**
Drivers to innovations: • Reach desired outputs with innovation (deliver infrastructure assets) • Reach desired outcomes (efficiency, effectiveness, quality, learning from projects)	**Preconditions to innovations:** • Leadership, visions, and commitment • Financial capabilities of organizations • Suitable collaboration form	**Inputs to innovations:** • Resources (capital investments, knowledge, human resources) • Volume of works or enough projects in a group	**Top enablers to innovations in multi-projects:** • A suitable contract forms • Knowledge exchange external and internal • Positive collaboration efforts • Influence of networks **Top challenges to innovations in multi-projects:** • Technical • Contract form • Innovation cost • Clients' organisation structure and size • Knowledge exchange with external parties • Time barrier • Clients' organisation demands	**Output of innovations:** • Proven-concept product/process innovations in projects **Outcome of innovations:** • Desired benefits (efficiency, effectiveness, quality, learning from projects)

Practical plan 1. Create awareness about innovation process	**Action plan 1 for suppliers** 1.1 Provide training/workshop on innovation process to organization and clients 1.2 Sharing lesson learnt of innovation development in professional knowledge sharing network 1.3 Actively participate in community networks for discussion forum, presentations, dialogues 1.4 Conduct frequent discussion with internal organization and external organization	**Action plan 1 for public clients** 1.1 Provide training/workshop on innovation process to organization 1.2 Sharing lesson learnt/success story of innovation development in organization and professional knowledge sharing networks 1.3 Conduct frequent discussion with internal organization and external organization to stimulate open formal and informal discussion
Practical plan 2. Develop basic knowledge of the latest technology trends.	**Action plan 2 for suppliers** 2.1 Assigning knowledge champion for special interest group 2.2 Organising regular knowledge sharing/presentation sessions and training sessions 2.4 Develop knowledge data base to share lesson learnt on innovations in projects 2.4 Following the latest development of technology in the market (local and worldwide) 2.5 Collaborate with research and knowledge institutions (Universities, research institutions)	**Action plan 2 for public clients** 2.1 Organising regular knowledge sharing sessions 2.2 Participating in knowledge community 2.3 Providing regular training and workshops 2.3 Collaboration with research and knowledge institutions (Universities)

Figure H.1: Framework Innov-Infra Part I (Own figure)

Part II – Facilitate the development and implementation of innovations		
Practical plan 3. Focusing on collaboration effort in projects/programme	**Action plan 3 for suppliers** 3.1 Actively networking with suppliers/organisation to identify suitable partners from the community networks 3.2 Maintain project teams especially for long-term projects/programme duration 3.3 Assign a dedicated clients engagement coordinator 3.4 Actively engage with clients in innovation development 3.5 Functions in project organisation mirror client's project's organisation 3.6 Maintain relationship with projects/programme team such as celebrating milestone together, using collaboration tools, promoting open communication, nurturing trust, team effort appreciation	**Action plan 3 for public clients** 3.1 Maintaining project teams especially for long-term projects/programme 3.2 Create a mirror function in project's level 3.3 Monitor collaboration process (e.g collaboration monitor) 3.4 Maintain relationship with projects/programme team such as celebrating milestone together, using collaboration tools, promoting open communication, nurturing trust, team effort appreciation
Practical plan 4. Programme/projects procurement should consider the following: • Procurement for innovations • Project delivery model support long-term collaboration • Utilizing functional requirement • Continuity of use of innovations • Award criteria supporting innovations	**Action plan 4 for suppliers** 4.1 Negotiate term and conditions on the contract to avoid disruption on innovation process (consider innovation elements) 4.2 Advise the client about the choice of collaboration form to promote innovation during market consultations/ discussion points with clients 4.3 Ensure continuity of innovation outside the programme	**Action plan 4 for public clients** 4.1 Selecting tendering procedure that promoting innovative solutions (competitive dialogue, innovation partnerships, SBIR) 4.2 Using Project delivery model promoting long-term collaboration between clients-suppliers and eliminating competition (framework agreement, alliance, with two stages approached with early contractor involvement) 4.3 Incorporating functional requirements 4.4 Engaging internal stakeholders to formulate realistic requirements for tender 4.5 Using award criteria based on quality and/or best value 4.6 Engaging suppliers at earliest possible in the programme/projects 4.7 Make consideration of further use of innovations outside the programme (intellectual property)
Practical plan 5. Development of business case should consider the following: • Lifecycle analysis • Bundling criteria • Reasonable time frame for innovations development	**Action plan 5 for suppliers** 5.1 Create an innovation map in the organization based on market trends, internal innovations, and clients' vision/goal to innovation 5.2 Suggest bundling criteria for projects during market consultations/ discussion sessions with clients/ project closure 5.3 Propose a reasonable time frame for innovation development 5.4 Suggest of bundling supply from various clients 5.5 Ensure inputs of innovations are guaranteed	**Action plan 5 for public clients** 5.1 Using life cycle perspective to justify the cost of innovation 5.2 Create sufficient demands to innovations by identifying assets to be bundled and develop bundling criteria 5.3 Guarantee inputs of innovations 5.4 Identify capability and capacity of the suppliers and cross sectoral actors (knowledge and network) by using formal mechanism (market consultation) or informal mechanism 5.5 Plan sufficient time to develop innovation (trial and error process/learning process)

Figure H.2: Framework Innov-Infra Part II (Own figure)